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HINDU ASTRONOMY

BY
G. R. KAYE

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PREFACE.

Although many distinguished Orientalists have written on "Indian Astronomy" there is no general account of this subject now available in the English language. The present attempt to supply a summary account of the astronomical material recorded in early and mediaeval Hindu works is therefore to some extent justified. In the matter of choice and treatment of topic the author of such a summary is always open to criticism. Many items of interest have to be omitted or touched upon very lightly, and the author's predilections may lead to undue emphasis on certain matters. In the present work such subjects as the Hindu calendar and Hindu chronology are not formally dealt with, since they are treated with some elaboration in various excellent books that are readily available; while the semi-religious and astrological aspects of astronomy have been dealt with more fully.

Although this summary account goes over old ground it is all based upon original texts. What has been accomplished is largely due to the encouragement of Sir John Marshall, Litt. D., C.I.E., etc., the Director-General of Archaeology in India, under whose auspices the Memoir has the advantage of being published.

I take this opportunity of recording my indebtedness to the Superintendent of Government Printing for the care and trouble taken in the production of a work entailing so many printing difficulties.

G. R. KAYE

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HINDU ASTRONOMY.

INTRODUCTION.

1. The history of Hindu astronomy has a history of considerable interest itself; and it is desirable to refer to this secondary history in some detail. It concerns chiefly a controversy tinged with acrimony, in which certain distinguished scholars took part—Laplace, Bailly, Playfair, Delambre, Sir William Jones, John Bentley and others. This controversy related chiefly to the question of the antiquity of the Hindu astronomical notions, first made known to Europe towards the end of the seventeenth century, and it unfortunately not only obscured the issues but gave an impetus in the wrong direction. It was not until the beginning of the nineteenth century that the attention of European scholars was drawn to those portions of Vedic literature that contain, in somewhat romantic and vague expression indeed, the true essence of indigenous Hindu astronomy.

2. In 1691 Giovanni Dominico Cassini published an account of certain astronomical rules brought from Assam by M. de la Loubière, and thus, as the most renowned astronomer at that time in France, gave a first advertisement; and soon after, in an appendix to the *Historia Regni Graecorum Bactriani* of T. S. Bayer, some account of Hindu astronomy was given, together with a dissertation by Leonard Euler on the Hindu year of 365 days 6 hours 12 minutes 30 seconds¹. In 1769 Le Gentil went to Pondicherry to observe a transit of Venus and in 1772 he published an account of the so-called Trivalore tables and Hindu astronomy generally. One of the more important results of this publication was the interest taken in it by "the illustrious and unfortunate" Jean Sylvain Bailly,² who, in 1787, published his *Traité de l'astronomie Indienne et orientale*. Bailly firmly believed in the great antiquity of the Hindu astronomical system which, he thought, supported certain views regarding the development of civilization that he was wedded to. His conclusions were often wrong and sometimes extravagant. He believed that the Hindus were the inventors of astronomy,

¹ J. BURGESS, *Journ. Royal Asiatic Soc.* 1893, p. 723.

² The first Mayor of Paris and President of the National Assembly in 1789: he was born in 1736 and guillotined in 1793.



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that their observations were direct and original, that their theory was simple and true, that their calculations, made from time immemorial were indeed less exact than ours but as reasonable and infinitely more simple and natural than those of Ptolemy, and that the Greeks of Alexandria had profited by the Indian notions but had mutilated their results¹.

3. Bailly's work attracted much attention and Laplace and Playfair seem to have been specially interested. Laplace at first thought that some of the Indian figures, said to be for 3102 B.C., were remarkably accurate; but later, in his famous *Mécanique Celeste* (1802), he revised this opinion: "The Indian tables," he writes, "indicate an astronomy in a state of considerable advancement, but everything leads us to believe that they are not of high antiquity. And here it is with pain that I differ from the opinion of an illustrious and unfortunate friend², whose death is a fearful instance of the inconstancy of popular favour..."

In 1790 Playfair wrote of Bailly's *Astronomie Indienne*: "The fact is....I entered on the study of that work, not without a portion of the scepticism, which, whatever is new and extraordinary in science ought to excite, and set about verifying the calculations and examining the reasons in it with the most scrupulous attention. The result was an entire conviction of the accuracy of the one and the solidity of the other." But this was not Playfair's final judgment and in 1817 he records a complete change of view. "When the astronomical tables of India first became known in Europe," he writes, "the extraordinary light which they appeared to cast on the history and antiquity of the East made everywhere a great impression; and men engaged with eagerness in a study promising that mixture of historical and scientific research, which is, of all others the most attractive. The ardour with which they entered on this pursuit, the novelty of the object and the surprise excited, may have led them further, in some instances, than the nature of the evidence when scrupulously examined, authorised them to proceed." He then goes on to explain that a more minute examination led the enquirers to doubt "the pretensions to high antiquity that they found in the astronomical books of the Hindus," and he refers to Delambre's arguments "that the data are nowhere quoted from which the Indian tables were computed and that there is no record, not even any tradition, of regular astronomical observations having been made by the Hindus."

In 1792 Playfair addressed the Asiatic Society⁴ and suggested a systematic search for works on Hindu mathematics and astronomy, the actual examination of the heavens in company with Hindu astronomers, and descriptions and drawings of the astronomical buildings and instruments still to be found in India, etc.

4. In the meantime (in 1789) Mr. S. Davis had made an analysis of the *Sūrya Siddhānta*. He noted that the obliquity of the ecliptic was given in that work as 24 degrees, assumed that this was the result of accurate observation and concluded that this observation had been made about 2050 B.C.⁵

¹ DELAMBRE, *Histoire de l'astronomie ancienne*, i. 416 f.

² Bailly.

³ *Trans. Roy. Soc. Edinburgh* ii, 1790, pp. 135—192.

⁴ *Asiatic Researches* iv, pp. 159—163.

⁵ *Asiatic Researches* ii, 238.

Sir William Jones¹ stepped in in his characteristic way: "I undertake to prove," he writes, "that the Indian Zodiac was not borrowed mediately or directly from the Arabs or Greeks." "The Brahmans," he says, "were always too proud to borrow their science from the Greeks, Arabs, Moguls, or any other nation of Mlechchas as they call those who are ignorant of the Vedas, and have not studied the language of the gods...." Of the idea of indebtedness to the Greeks they "All seemed to think it a notion bordering on phrenzy." Again he tells us that "they are also of opinion that the vernal equinox oscillates from the third of Mina (Pisces) to the twenty-seventh of Mesha (Aries) and back again in 7200 years" and concludes that this theory was based upon an observation made in 1181 B.C. ! In reply to Playfair's suggestions regarding a systematic enquiry Jones naively writes: "Concise answers to his questions will be given in my next annual discourse," but afterwards he confessed that he had "offered ample stipends to any Hindu astronomer who could name in Sanskrit all the constellations that he should point out, but failed."

5. In 1799 John Bentley² controverted Bailly's assumption of extreme antiquity for the Hindu astronomy, and, although Bentley made mistakes and was an injudicious controversialist³, his main thesis was fully established. The most important of those Hindu astronomical works that have been in vogue for the last thousand years or so is the *Sūrya Siddhānta*. In its present form it probably dates from about A.D. 1000 but it claims immense antiquity. "The sun himself delivered...the system of the planets...when but little of the golden age was left," which, according to Hindu reckoning, was some two million years ago⁴. But the astronomical elements in the text imply a much later date, namely the commencement of the Kali Yuga, or 3102 B.C. when all the planets were supposed to be in conjunction. Now the question was: Does this date, 3102 B.C. correspond to actual observations by Hindu astronomers at that time? Bailly thought it did and at one time Laplace and Playfair agreed with him, but as a matter of fact nothing approaching a general conjunction obtained at that period, as the following figures show:

Position of the planets at Ujjain, Midnight, February 17-18, 3102 B.C. with reference to the beginning of the Hindu sphere.

Sun.	Mercury.	Venus.	Mars.	Jupiter.	Saturn.	Moon.
-7° 51' 48"	-41° 3' 26"	+24° 58' 59"	-19° 19' 26"	+8° 36' 36"	-28° 1' 13"	-1° 33' 41"

¹ *The works of Sir William Jones*, iv. 'On the chronology of the Hindus,' p. 1 f.; 'supplement to the essay on Indian chronology,' p. 48 f.; 'On the antiquity of the Indian zodiac,' p. 71 f.

² 'On the antiquity of the *Sūrya Siddhānta* and the formation of the astronomical cycles therein contained.' *Asiatic Researches*, vi, pp. 537-588.

³ "He thoroughly misapprehended the character of the Hindu astronomical literature thinking it to be in the main, a mass of forgeries framed for the purpose of deceiving the world respecting the antiquity of the Hindu people.... Little of his work would stand the test of a thorough examination." *Journ. Am. Oriental Soc.* 1858, p. 168.

⁴ *Sūrya Siddhānta* i, 2-9.

This table¹ may be said to dispose of the question of observations at 3102 B.C. or thereabouts; but there remained to be settled the time at which the observations, on which the tables and calculations were based, actually did take place. The above considerations lead to the conclusion that the period of conjunction was calculated backwards from a certain other period at which the actual positions of the planets must have been known approximately at least. Bentley attempted, with some success, to find this later period. He showed by a table "the gradual decrease of the errors of the *Sūrya Siddhānta*, from the year 3102 before Christ, down to A.D. 999, and also for two periods later, in order to show the increase of the errors again in an opposite direction."

Bentley's table of errors in the positions of the planets as calculated according to the Sūrya Siddhānta

—	B.C. 3102.	B.C. 2102.	B.C. 1102.	B.C. 102.	A.D. 538.	A.D. 1091.
Mercury	+33° 26'	+25° 10'	+16° 54'	+8° 38'	+3° 22'	—1° 12'
Venus	—32° 44'	—24° 38'	—16° 31'	—8° 15'	—3° 15'	+1° 14'
Mars	+12° 6'	+9° 27'	+6° 47'	+4° 8'	+2° 27'	+0° 58'
Jupiter	—17° 3'	—12° 44'	—8° 26'	—4° 7'	—1° 22'	+0° 41'
Saturn	+20° 59'	+15° 43'	+10° 28'	+5° 12'	+1° 50'	—1° 45'
Moon	—5° 53'	—3° 51'	—2° 9'	—0° 53'	—0° 19'	—0° 1'
Moon's Apsis	—30° 11'	—23° 10'	—16° 8'	—9° 6'	—4° 36'	—0° 43'
Moon's Node	+23° 38'	+17° 59'	+12° 31'	+7° 3'	+3° 33'	+0° 32'

From an average of the results Bentley concluded that the *Sūrya Siddhānta* dated from A.D. 1091. This may be accepted as a rough approximation to the correct date, but taking the average of such a set of figures is unsound, as they are not of equal value and should be 'weighted'; and it is assumed that correct observations were made at some particular period, whereas the error in observation was possibly sufficient to make Bentley's conclusion wrong by some 300 years. However, the main conclusion is undoubtedly more or less correct, and since Bentley's time a great deal of evidence that corroborates the view as to the comparative modernity of the *Sūrya Siddhānta* has come to hand.

6. In 1807 the scholarly Colebrooke quietly introduced the suggestion that Hindus were in some ways indebted to the Greeks.² Montucla had, indeed, made certain statements on this point,³ but they had been brushed aside by

¹ Such tables should, however, be interpreted with circumspection. The figures themselves are not perfectly certain and their verification would be a waste of labour now; but they may be accepted as illustrating the undoubted fact that there was no general conjunction at 3102 B.C.

² "On the Indian and Arabian divisions of the zodiac." *Asiatic Researches* IX, 1807, pp. 323—376; and *Essays* ii, pp. 321—373.

³ *Histoire des mathématiques*, 1799—1802, ii, iii.

Sir William Jones¹. Colebrooke wrote: "None of the astronomers whom I consulted were able to point out in the heavens all the asterisms for which they had names....I apprehend that it must have been the Arabs who adopted (with slight variations) a division of the zodiac familiar to the Hindus...." But he also points out that several Hindu astrological notions were confessedly received from foreign nations (p. 371); and he notes the correspondence between the Hindu and Greek signs of the zodiac, the *dreshkānas* of the Hindus and the *dekanoi* of the Greeks, and suggests that the term *Yavanāchārya* refers to a Greek author. "By their own acknowledgment," he writes, "they have cultivated astronomy for the sake of astrology; and they may have done it with the aid of hints received from the same quarter from which their astrology is derived." (p. 373). In 1817 Colebrooke gave further evidence of the communication of the Hindus with the west², and in the same year Delambre's last and perhaps most celebrated work, which pays considerable attention to the astronomy of the Hindus, appeared³. Delambre's opinion carried great weight and after carefully examining Bailly's and Bentley's views he gave it almost wholly against Bailly. In 1825 Bentley published his *Historical View of Hindu Astronomy*, a valuable book, but marred by intemperate language and impatience with all opposition. Even Colebrooke was roused by it to reply, in the *Asiatic Journal* of 1826⁴.

7. During this period of controversy on matters of fictitious importance there had been a certain amount of research in more legitimate directions. Sir W. Barker, Commander-in-Chief of the Bengal Army, had examined with some care the instruments of Jai Singh's observatory at Benares⁵; and shortly afterwards (1795) Playfair had suggested the line of research already referred to. In 1799 Hunter gave a detailed description of the instruments of Jai Singh's observatory at Ujjain. Unfortunately these investigations also masked the real issue, for it was popularly believed that Jai Singh's astronomy was an off-shoot of Hindu astronomy proper, and it was not realised that it was a direct result of Muslim teaching. The real foundation of a proper knowledge of the history of Hindu astronomy was laid by Weber (1860—1868), Whitney (1858) and Thibaut (1877—1889). Weber gave us the *Jyotisha Vedāṅga*, etc., Whitney a translation, together with a critical commentary, of the *Sūrya Siddhānta*, and Thibaut the *Pañchasiddhāntikā* of Varāhamihira; and with these should be mentioned Sachau's translation (1888) of Albīrūnī's *India*. These contributions settled definitely the question of the connexion between the later Hindu astronomy and that of the Greeks; and the attention of the orientlists was consequently directed to the earlier periods that had been designated Vedic and post-Vedic. In 1893 Jacobi and Tilak independently suggested that the Vedic works contained important astronomical evidence of their own anti-

¹ *Works*, iv, 71 f.

² *Algebra with Arithmetic and Mensuration from the Sanskrit*, etc., 1817, pp. xxx—xxxiv.

³ *Hist. de l'astron. ancienne*, 1817, i, 400—517.

⁴ *Essays* ii, 366—374.

⁵ See my *Astronomical Observatories of Jai Singh*, pp. 64—65.

quity; but their views were strongly opposed by Whitney, Oldenberg and Thibaut. Thus was started another controversy, which, like the earlier one, was also flavoured with a certain amount of personal virus; for Whitney, whose knowledge of Sanskrit literature and of astronomy was unrivalled, accused Jacobi of disingenuousness. The general result is that while many European orientalists reject Jacobi's and Tilak's hypotheses, in India itself they are popular. But even those who oppose them must acknowledge that Jacobi and Tilak have made the subject of controversy extremely interesting.

In the following chapters considerable attention is paid to the earlier or pre-Greek period of Hindu astronomy and the later material might, with some propriety, have been excluded altogether. However, not only has this later period a sort of traditional claim to attention, but its study often helps to elucidate obscure points of the earlier period; for the Hindus, when they absorbed the western ideas, often gave them an Indian setting; and also the period of absorption is one of such extreme interest in the history of civilization that any light thrown upon it from the east is valuable. Therefore this later system has been analysed in some detail and a brief account of the chief Hindu astronomers who expounded the western astronomy has been included.

CHAPTER II.

Periods.

8. The earliest sacred works of the Hindus, known as the Vedas, contain many astronomical references of interest, and these references have a special value, largely due to the position those works hold in the history of civilisation; while the astronomical records in the works subsidiary to the Vedas—the Brāhmaṇas, Upanishads, etc.—are also of considerable historical interest. The earliest formal work on Hindu astronomy that has come down to us is probably the *Jyotiṣa Vedāṅga*, which claims by its title a fairly close connexion with the Vedas. Spread over a considerable period are the great epics the *Mahābhārata* and *Rāmāyaṇa*, which also contain astronomical matter of interest, and corresponding in point of time with the later portions of these works are the *Purāṇas*, which give in a popular form some account of the current astronomy. Later than the *Jyotiṣa Vedāṅga*, possibly by some centuries, come the earliest of those text books of the *Sūrya Siddhānta* type, which, with some modification in matters of detail, have continued in use for the last fifteen hundred years.

9. There is a very marked differentiation between the works of the type of the *Jyotiṣa Vedāṅga* on the one hand, and those of the type of the *Sūrya Siddhānta* on the other, and this differentiation is not merely one of time—it is so fundamental that continuity of development appears to be altogether out of the question. Somewhere between the Vedāṅga period and the period of the composition of the original *Sūrya Siddhānta* a distinct break occurred—the old methods and rules were discarded and new method were introduced and new phenomena treated. The time of this break in continuity of development is known, at least approximately, and it may be tentatively stated to be about A.D. 200—500. This forms a convenient epoch in the history of Hindu astronomy, and, for purposes of exposition, it is proposed to utilise it in dividing the material available into two main sections, which with their subdivision may be roughly tabulated thus¹ :—

Principal sources of information.	Conjectural dates.
A ₁ Vedas, Brāhmaṇas, etc.	B.C. 1200 — B.C. 400.
A ₂ Jyotiṣa Vedāṅga, etc.	B.C. 400 — A.D. 200.
AB Mahābhārata, Purāṇas, etc.	B.C. 400 — A.D. 400.
B ₁ Works of Āryabhaṭa, Varāha Mihira, etc.	A.D. 400 — A.D. 700.
B ₂ Later Siddhāntas, etc.	A.D. 700 — A.D. 900.

This scheme must not, however, be taken as literally exact: it is simply a convenient one that exhibits some parallelism with the actual facts.

10. The sources from which our information regarding the astronomy of the earlier period is taken are the texts of the four Vedas, the Brāhmaṇas, and the Upanishads. For general information about these works the reader

¹ It will be convenient at times to refer to these sections by the names of their principal works or other characteristics: e.g., the Vedic period (A₁), the post-Vedic or Vedāṅga period (A₂), etc.; but no strict classification according to such nomenclature will thereby be implied.

is referred to the excellent books by Professors Barnett and Rapson, and others. It may, however, here be briefly explained that of the four Vedas the Rigveda is by far the most important historically; and that a Brāhmaṇa or religious manual, and a Sūtra or collection of rules are attached to each Veda; and that the Brāhmaṇa is further divided into three rather vague orders of which the Vedānta or Upanishad is chiefly concerned with theosophical speculations. The Vedāṅgas are subsidiary works of later date dealing with the several branches of secular knowledge.

The chronology of these works is somewhat as follows:—

B.C.1200—B.C.1000	. . .	Period of Vedic collections—Rig Veda, Sāma Veda, Yajur Veda and Atharva Veda.
B.C.800—B.C.600	. . .	Period of the Brāhmaṇas.
B.C.600	. . .	The earliest Upanishads.
B.C.600—B.C.200	. . .	Period of the Sūtras.
B.C.200—A.D.200	. . .	Period of the Vedāṅgas.

11. The *Mahābhārata*, *Rāmāyaṇa* and the Purāṇas occupy a peculiar position in the history of Hindu astronomy, for while they, no doubt, embody certain ancient astronomical traditions, they contain a good deal that does not obviously appertain to the earlier period. On other than astronomical grounds the later limit of portions of the *Mahābhārata* has been fixed at about A.D. 400 and the texts of the Purāṇas generally contain unambiguous evidence that they are at least as late as that date. Citations from the epics and the pseudo-historic Purāṇas must therefore be employed with circumspection.

For the post-Vedic period (A₂), which is marked by a certain amount of formal astronomy, we have the *Jyotiṣa Vedāṅga*, the *Paitāmaha Siddhānta* and the *Sūryaprajñapti*, all of which exhibit schemes that are essentially similar. Considerable antiquity has been claimed for the first of these, but it probably belongs to the beginning of the Christian era or thereabouts. For the *Paitāmaha Siddhānta* we have a definite date, for it employs the epoch of 2 Śaka (=A.D. 80). The *Sūryaprajñapti* contains astronomical methods that are quite as antiquated as those of the *Jyotiṣa Vedāṅga* but there are indications that lead to the conclusion that it is probably of a much later date.

12. The second period (B) may be conveniently divided into two sub-periods, of which the earlier one only has historical importance. This (B₁) may be considered to coincide pretty closely with the period of the Gupta dynasty (A.D. 320—650) and it embraces the most celebrated of the Hindu astronomers—Puliśa, Āryabhaṭa, Varāha Mihira and Brahmagupta and their contemporaries. In the history of civilization generally this period is of exceptional interest. In India the period was productive of many important work in mathematics, astronomy, astrology, medicine, poetry and the drama. The following dates may be noted:—

- A.D. 476 Āryabhaṭa born.
- A.D. 505 Epoch of the Romaka Siddhānta.
- A.D. 587 Varāha Mihira died.
- A.D. 598 Brahmagupta born.
- A.D. 628 The *Brāhmasphuṭasiddhānta* composed.
- A.D. 650 Epoch of the *Khaṇḍakhādya*.

The second sub-period, which extends from about A.D. 700 to the present day, is of subordinate interest altogether. Bhāskara is the only conspicuous figure and his importance has been somewhat exaggerated. His *Siddhānta Śiromaṇi* is, however, one of the best known of the Hindu works and will be occasionally referred to in the sequel.

13. The more marked astronomical features of these periods are—

A₁ (Vedic). A year of 360 days with an occasional intercalary month, not clearly defined; division of the ecliptic into 27 or 28 nakshatras; the absence of any explicit reference to the planets; etc.

A₂ (Post-Vedic). A five-year cycle consisting of 5×360 days; the *tithi* equals one-thirtieth of the synodic month and $61/62$ of a natural day; the ecliptic is divided into 27 equal or 28 unequal nakshatras; the difference between the longest and shortest days is given (for Ujjain) as 4 hours 48 minutes; there is no definite treatment of the motions of the planets.

B₁ (A.D. 400—700). The motions of the planets dealt with in some detail by the method of epicycles: parallax of the sun and moon; eclipses: direct and oblique ascensions; length of day (correct theory); heliacal settings and risings; gnomonics; the sine function introduced; formal astrology; the nakshatras become of subordinate interest; precession inadequately treated.

B₂ (A.D. 700—1000). The same topics with more elaborate detail, the excentric introduced; precession treated as a libration; but the fundamentals and methods are the same as in the previous period.

CHAPTER III.

Early texts.

14. It is not altogether an easy matter to give a strictly logical exposition of our subject. The textual, historical and logical aspects are to some extent in conflict. Certain texts carry much more weight than others; topics occur and recur, and there is a good deal of overlapping; the chronological order of the texts, or portion of them is not always well defined. Therefore, at the risk of a certain amount of repetition, it is proposed, in the first place, to give a sort of astronomical epitome of the more important texts, and afterwards the material, previously dealt with rather summarily, will be collected, arranged and discussed in more detail, under suitable headings.

Crude astronomical notions must have been, in connexion with sacrificial ritual, common property at a very early stage in India. The morning and evening sacrifices, seasonal and yearly sacrifices, and those at new and full moon necessitated a calendar of sorts and some knowledge of astronomy. As the earliest astronomical text-book says: "Since the Vedas teach the aim of sacrifice and sacrifices follow the order of time, therefore he who knows astronomy, that is, the science of time order, knows the sacrificial rites."

In the Vedas the astronomical statements are sometimes vague. Often the heavenly bodies are personified—but the differentiation between the god and the object is not very marked; and it is possible that certain names that have been handed down were originally connected with astronomical phenomena, although the connexion is now obscured. The romantic vagueness of many of the passages, of the Rig-Veda particularly, naturally leads to speculation—sometimes extravagant, but often of considerable interest.

15. In the early works direct references to the subject of astronomy are very few, and no reference to any work on astronomy occurs in the *Saṁhitās* or *Brāhmaṇas*. In the *Yajur Veda* (XXX, 10) the *nakshatra darśa* (star-gazer or astrologer) is mentioned as one who would bring 'insight' if offered up as a sacrifice; and in the same list of human victims (XXX, 20) the *gaṇaka* (calculator or astrologer) is said to bring 'power' to the sacrificer. The *Chhândogya Upanishad* gives (VII, 1², 2¹ 7¹,) lists of subjects known to Nārada and these lists include *nakshatra vidyā* (astronomy), and *rāśi* (quantity or number). *Āpastamba* says¹ "The Veda has six *āṅgas*, the kalpa of the Veda, the treatises on grammar, astronomy (*jyotiṣa*)²; etymology, phonetics and metrics" and these are known as the *Vedāṅgas* or 'limbs of the Vedas.' In the *Jaina Sūtras*³ astronomy is said to be one of the principal accomplishments of the priest.

¹ *Dharma Sūtra* iv, ii, 8¹⁰.

Generally speaking, in India, astrology and astronomy were two branches of one science. The term *Jyotiṣa* applied to both astrologer and astronomer, and the *Jyotiṣa* had to know astronomy, judicial astrology (*horā*), and natural astrology. Judicial astrology is sub-divided into nativity (*Jātaka*), prognostics for journeys (*yātrā*), and for weddings (*vivāha*). (H. JACON' *FRS* iv. 800). See also the *Bṛhat Saṁhitā*, ch. I.

² *SBE* xxii, 221.

Some passages accord a sort of approval of astrology but there are others that seem to imply that it is not quite respectable. Baudhāyana says¹ "Now (follow the offences) which make men impure....gaining one's livelihood by astrology and so forth." The laws of Manu teach² that for certain purposes "he who subsists by astrology....must be carefully avoided," and the astrologer is placed in rather doubtful company; and the ascetic is forbidden³ to seek alms "by skill in astrology and the other āṅgas of the Veda." The Mahābhārata also seems to slight those who 'live by the stars.'⁴ The *Kauṣīliya Arthaśāstra* states that "faith in the auspiciousness of lunar days and stars" is one of the "obstructions to profit" and also that "wealth will pass away from that childish man who inquires most after the stars."

The *Fo-sho-ping-tsang*⁵ forbids "star-gazing and astrology, forecasting lucky and unfortunate events by signs, etc." and in the Tevijja Sutta we are told⁶ that "some Samana Brahmans...continue to gain a livelihood by such low acts and such lying practices as these: that is by predicting 'There will be an eclipse of the moon...There will be an eclipse of a planet. The sun and moon will be in conjunction.'"⁷

THE RIG VEDA.

16. The point of departure in the study of almost any section of knowledge in which India is deeply concerned is the *Rig Veda*; and in this India is indeed fortunate, for of all the literature of early civilisation the *Rig Veda* is perhaps the most fascinating to the philosophic enquirer, and, in particular, the Vedic hymns that are devoted to celestial phenomena are amongst the most beautiful. But these hymns are concerned with the attributes and functions and praise of certain divinities who are only very loosely connected with heavenly bodies or phenomena; and the astronomical information exhibited in these hymns is by no means their essential part. Much as we should like to dwell on the hymns to Sūrya, Savitrī, Mitra and the other Ādityas we are constrained by the nature of the present work to be content, for the time being, with culling from them a few dull facts.⁷

In the *Rig Veda* the sun is the source of light, out-strips all in speed⁸, measures day and night,⁹ drives away the stars and night like thieves¹⁰. The sun's chariot has seven¹¹ horses generally but occasionally five, or six, or a thousand¹². Occasionally the sun was overspread with darkness by Śvarbhānu, which was dissipated by Atri and by prayer¹³.

¹ SBE, xiv, 220.

² iii, 162.

³ vi, 50.

⁴ W. HOPKINS *The Great Epic of India*, p. 15.

⁵ SBE xix, 296.

⁶ RHYS DAVID'S *Buddhist Suttas*, SBE, xi, 197.

⁷ It has been suggested to me that the Buddhistic opposition to astronomical and astrological lore was due to anti-Magian feeling; but see also § 19: the *Jātakas* appear, at least, to tolerate it. See also page 128. Strabo refers (*Geog.* xv, 1) to the Brahmans as occupying themselves with physiology and astronomy.

⁸ But see Appendix ii.

⁹ i, 50^a.

¹⁰ i, 50^b.

¹¹ i, 50^c.

¹² i, 50^d; i, 164^a; vi, 44^a; etc.

¹³ v, 62.¹

¹⁴ v, 40^b; iv, 28^a; v, 33^a. See also x, 27^a; x, 37^a; x, 138^a; LUDWIG'S *Rig Veda* 6 x; WHITNEY JAOS 13, lxi and 16 lxxxii; and SBE xli, p. 65.

The moon appears to order the seasons and is continually born again. The sun and moon 'ascend alternate,' and move 'in close succession'¹ but the moon plays a subordinate part throughout, although Soma (afterwards a Moon-God) is, from a non-astronomical point of view, of supreme importance.

The year has twelve months and 360 days, and is divided into four quarters of 90 days each². There is no definite reference to a five year cycle³, nor any explicit reference to an intercalary month⁴. The account of the Ribhus reposing for twelve days⁵ has been supposed to imply a lunar year of 354 days with the 12 additional days making 366 in all.

Jacobi thinks that the 'Frog hymn' indicates that the year commenced with the summer solstice⁶, and that another hymn marks the beginning of the year with the sun in the asterism Phalgunī⁷, and the summer solstice occurred in the constellation usually identified with Phalgunī about 4000 B.C. In another passage⁸ Tilak sees a reference to the heliacal rising of Sirius at the vernal equinox, and Kern sees a similar reference to Canopus in i, 170 & 180.

It would be stupid to insist that the Vedic seers had no knowledge of the planets; but the fact that there is no explicit reference to the planets in any of the Vedic writings is undisputed. A great deal of ingenuity has been exercised in trying to discover references that imply the planets or a knowledge of them but without any assured success. The implied connexion suggested in most of the texts cited is due to the mention of the numbers 'five' or 'seven' "the seven sages with five Adhvaryus⁹, 'the five ukshāṇas,¹⁰" "the seven Ādityas"¹¹. Bṛihaspati was later on the name for Jupiter and it is possible that in the Rig-Veda the planet is meant by Bṛihaspati¹² but this is only conjecture. 'The cloud-born Vena'¹³ has been equated with Venus but without general acceptance. According to Tilak¹⁴ the use of the terms Śukra¹⁵ and Manthim implies a knowledge of the planets, and the 'thirty-four with light-like nature' Ludwig thinks includes the seven planets and the 27 nakshatras.¹⁶

Of constellations there are few definitely mentioned: Aghās and Arjunī¹⁷ are usually identified with the adjacent asterisms Maghā and Phalgunī; Tishya may be a special star¹⁸ although Sāyana identifies it with the sun; and the seven Rishis, in one passage at least,¹⁹ probably denote the 'Great Bear,' and the Rikshas (Bears) in another case²⁰ probably denote the same constellation. Tilak sees²¹ references to Sirius and Orion in certain passages.²²

¹ x, 85¹⁸.

² But see iii, 55.¹⁹

³ i, 25⁸ has been supposed to imply an intercalary month. See also § 32.

⁴ iv, 33⁷ and ZIMMER *Altindisches Leben*, 366.

⁵ vii, 103⁹.

⁶ x, 85¹².

⁷ i, 105¹¹.

⁸ iii, 7⁷.

⁹ i, 105¹⁰.

¹⁰ ix, 114².

¹¹ iv, 50⁴.

¹² x, 123².

¹³ i, 164¹¹; i, 164¹⁰; i, 155⁴.

¹⁴ Orion, p. 162.

¹⁵ iii, 32²; ix, 46⁴.

¹⁶ x, 55² See also i, 162¹.

¹⁷ x, 85¹².

¹⁸ v, 54¹²; x, 64².

¹⁹ x, 82².

²⁰ i, 24¹⁰ ?

²¹ Orion, 96 et seq.

²² x, 14¹¹; x, 86²²; i, 105¹¹; i, 161¹², etc.

OTHER SAMHITĀS. ~

17. The YAJUR VEDA (*Taittirīya Samhitā*) gives a list of twenty-seven asterisms or nakshatras, commencing with Krittikā¹. It also states definitely that "the full moon in Phalgunī is the beginning of the year."² Thus the *Taittirīya Samhitā* gives us the two most important contributions to Vedic astronomy. Nakshatra lists are also given in the *Maitrāyaṇī* and *Kāthaka Samhitās* and in the *Atharva Veda*. The topic is of sufficient importance to be dealt with in a special section. The passage relating to the year beginning with the full moon in the Phalgunī has by Jacobi been combined with the notion that the year began with the summer solstice; the combination, which, however, is by no means a legitimate one, gives a date of about 3000 B.C.

The *ATHARVA VEDA* refers explicitly to a thirteenth month of 30 days³, which possibly implies a five year cycle of $5 \times 360 + 30 = 1830$ days, such as is exhibited in the *Jyotisha Vedāṅga*, etc. The names of the year as given in several of the *Samhitās* are of no astronomical value⁴. The *Atharva Veda* also mentions eclipses on several occasions⁵, and introduces Rāhu⁶, the demon of eclipses: Soma and Rudra remove the eclipse.⁷ The nakshatra list of the *Atharva Veda* consists of 28 asterisms and is, apparently of an astrological character.⁸ There is a possible reference to Sirius and to the three stars of Orion's belt⁹; and possibly Śakadhūma, 'the king of the asterisms,' is the Milky Way.¹⁰

SUBSIDIARY TEXTS.

18. The *Brāhmaṇas* add very little of astronomical value. There are definite references to a thirteenth month of thirty-five¹¹ days or thirty-six days.¹² The *Krittikās* are said to rise in the east and the seven *Ṛikshas* in the north, and *Dikshit* cites the former as implying that the *Krittikās* (? the *Pleiades*) were on the equator and deduces a date of 3000 B.C.¹³ The *Rohiṇī* myth is, in the Greek fashion, transferred into a star picture¹⁴.

The *Upanishads* add nothing of special interest except, perhaps, a reference to the 'fixed' (*dhruva*) pole star,¹⁵ which Jacobi identifies with *Draconis* and so deduces the date 2780 B.C. The nakshatras appear to occupy equal spaces of $13\frac{1}{2}$ degrees and the year appears to be divided at the beginning of *Maghā* or the end of *Āśleshā*¹⁶. The terms *Ketu* and *Graha* are employed¹⁷ but not with any definite astronomical denotation.

¹ iv, 4¹⁰.² vii, 45.³ v, 6⁴; xii, 3⁵.⁴ See the *Taittirīya Samhitā* v, 5⁷. These names vary in number from two to six.⁵ iii, 2¹; ii, 10².⁶ ix, 9¹⁰.⁷ iii, 2³.⁸ xix, 7^{2, 5}.⁹ vi, 80¹².¹⁰ vi, 128¹.¹¹ ŚB, ix, 1, 1⁴². *SBE*, xliii, 167.¹² ŚB x, 5, 4¹. *SBE*, xliii, 383.¹³ ii, 1, 2^{2, 4}. See §32, xii; & *Ind. Ant.* vol. xxiv p. 245. ¹⁴ AB iii, 33².¹⁵ MBU i, 4. Hipparchus says, 'as regards the north pole, Eudoxus is in error in stating that "there is a certain star which always remains in the same spot."' HEATH *Aristarchus of Samos*, p. 8.¹⁶ MBU vi, 14. *SBE*, xv, 316.¹⁷ MBU vii, 6. *SBE*, xv, 340.

THE JĀTAKAS.

19. It has already been pointed out that Buddhist texts are often severe in their condemnation of star-gazing, astrology and such practices as the foretelling of eclipses; but the *Jātakas* contain fairly numerous references to astronomical matters. In number 20 the Kappa or era, with its four era miracles, is mentioned, the first of these miracles being 'the sign of the hare in the moon, which will last the whole era.'¹ In no. 48 a charm is to be repeated at a certain conjunction of the planets, and the magician is made to say "It will be a year before the requisite conjunction of the planets takes place again." In no. 474 the following verse occurs:—

The hour and moment suit not: so wait
Fit conjunction of the planets in the sky.

Similar references to conjunctions of the planets are made in nos. 481 and 522, and in no. 481 the goblin on releasing the prince says: "Go forth from my hand, even as the moon from the jaws of Rāhu;" and such references to the demon of eclipses recur pretty often.²

THE MAHĀBHĀRATA.

20. The *Mahābhārata*, the longest epic poem known, has, as a whole, no definite date, but, with a considerable probable error, the period of composition may be stated to range from 400 B.C. to A.D. 400. It contains interesting material of a quasi-astronomical nature.

The five-year cycle is mentioned and it is stated (vi. 52³) that there would be an excess of two months in five years, and of five months six days in 13 years. The Krita age is also mentioned without specifying the length of the period, and it is said that it will come again when the sun, moon, the nakshatra Tishya (=Pushya) and Jupiter meet in one sign (iii. 190⁹⁰)³.

The nakshatras are generally 27 in number (see I 66¹⁶, XII. 207²⁴, XII. 343⁵⁷) but 28 seem occasionally to be implied (e.g., in V. 110¹⁸, IX. 34⁹); and there is a reference to the disappearance of Abhijit: "The lady Abhijit, the younger sister of Rohinī, being jealous, has repaired to the woods to perform austerities, and I am at a loss to form a substitute for the fallen star." (iii. 230²). "Time was arranged by Brahman to begin with Dhanishtha" (iii. 230¹⁰) but the nakshatras are said to begin with Śravana (xi. 44²); and the change was made by Viśvāmitra "who in anger created a second world and numerous stars⁴ beginning with Śravana" (i. 71).

The month begins with the bright fortnight (new moon to full moon) and a half month contains 14, 15 or 16 days. An eclipse occurring on the 13th day is mentioned (vi. 3¹²).

¹ See also No. 513; "To Indra once like some poor Brahman drest The hare did offer its own flesh to eat. Thenceforth its form was on the moon imprest. That gracious orb as Yakks now we greet."

² e.g., in nos. 25, 490, 537.

³ Pushya is supposed, more or less, to coincide with Cancer, and Berceus predicted that the world would be burnt when all the planets came together in Cancer. (See BOUCHÉ LÉCLERCQ, *L'Astrologie grecque*, p. 33; and A. JAKOBSEN, *ERE*, i. 183.) See also the *Samdhyana*, i. 60.

The planets are mentioned by name in the following order: "Venus, Jupiter, Mercury, Mars, Saturn, Rāhu and the other planets." (ii. 11²⁷). The stars though "so small in consequence of their distance, are large" (iii. 42²⁴). This, Hopkins thinks, is the most surprising astronomical statement in the epic¹. A man star picture is constructed (xiii. 110³).

THE RĀMĀYAṆA.

21. The *Rāmāyaṇa* of Vālmīki was probably composed in the fourth or third century B.C. but it is not free from more recent additions. It contains a number of astronomical illustrations of which the favourite seems to be the Rohiṇī Moon myth.² A number of the nakshatras are mentioned and generally with reference to the position of the moon³ and in one case Pushya appears to be equated with Mīna (Pisces)⁴. Of particular constellations the Great Bear and Trisāṅku occur⁵. The planets Mars, Mercury, Jupiter and Venus are definitely mentioned⁶. One whole canto is devoted to the glory of the sun⁷. Rāhu, as the enemy and devourer of the moon, is mentioned on several occasions⁸, but Ketu does not appear to occur. Meru is stated to be the best of mountains and is generally coupled with some other mountain range, e.g., Vindhya, Himavān⁹.

22. THE PURĀṆAS.—The chief characteristic of the Purāṇas from our point of view is perhaps connected with cosmological notions. Jacobi writes¹⁰ "Notwithstanding, or rather because of its visionary character, Paurāṇic cosmography became, as it were, an article of faith. The general belief in it was not shaken even, by the introduction of scientific astronomy, though the astronomers tried to model the traditional cosmography on the basis of their science." The following is condensed from the *Viṣṇu Purāṇa* (ii. 29): The seven great islands are surrounded by seven great seas. Jambū-dvīpa is the centre of all these, and in the centre of this is the golden mountain Meru. The height of Meru is 84,000 yojanas and its depth below 16,000. Its diameter at the summit is 32,000 and at its base 16,000; so that this mountain is like the seed cup of the lotus of the earth... The orbit of the sun is 100,000 yojanas from the earth and that of the moon an equal distance from the sun. At an equal distance above the moon is the sphere of the nakshatras. Mercury is 200,000 yojanas beyond, Venus 200,000 further still, Mars 200,000, Jupiter 200,000, and Saturn 250,000 yojanas beyond Jupiter. The sphere of the seven Rishis is 100,000 yojanas beyond and at the same distance above is Dhruva, the pivot or axis of the whole planetary circle. Beyond Dhruva are the four heavens... On

¹ Heraclides (350 B.C.) taught that "each star is also a universe or world, suspended in the infinite ether, and comprising an earth, an atmosphere and an ether." HEATH, *Aristarchus of Samos*, p. 254.

² i, 1; ii, 16, 114, 118; iii, 46, 49; iv, 35; v, 33.

³ i, 19, 71; ii, 2, 4, 8, 16, 25, 26; iii, 46; iv, 16.

⁴ i, 19.

⁵ i, 60; ii, 25, 41, 110; vi, 4.

⁶ ii, 41, 100; iii, 49; iv, 12; vi, 4, 24, 54, 103.

⁷ vi, 106.

⁸ ii, 4, 114; iii, 27, 37, 64; iv, 22; vi, 71. See also appendix ii.

⁹ iv, 38, 42, 46.

¹⁰ ERE iv, 160.

Dhruva rest the seven great planets, and on them depend the clouds. As Dhruva revolves it causes the moon, sun and stars to turn round also, and the nakshatras follow in its circular path: for all the heavenly bodies are, in fact, bound to the polar star by aerial cords....¹

The order and distances of these spheres from the earth are—

	Yojanas.		Yojanas.
Sun	100,000	Mars	900,000
Moon	200,000	Jupiter	1,100,000
Nakshatras	300,000	Saturn	1,350,000
Mercury	500,000	Seven Rishis	1,450,000
Venus	700,000	Dhruva	1,550,000

This order was not strictly followed by the later astronomers who placed the sun in its correct relative position and the nakshatras or stars beyond the furthest planet, and omit the seven Rishis and Dhruva. Besides the five planets; Rāhu and Ketu are mentioned, and each of the seven has a chariot drawn by eight horses (VP. ii.¹²).

It is implied that the winter solstice takes place at the beginning of the month Tapas (Māgha), and an equinox s, apparently, supposed to take place in Kṛittikā or Viśākhā (VP. ii. 8).

There is also a reference to the recurrence of the Kṛita age similar to that given in the epic.

The seven Rishis.—One of the most extraordinary astronomical theories that occurs in Hindu literature is connected with the seven Rishis, which are generally identified with the Great Bear. The principal authorities are the Paurāṇic texts and Varāha Mihira. The following is a Paurāṇic version of the theory: "The seven Rishis (were situated) equally with regard to Pushya while Pratīpa was king. At the end of the Āndhras, who will be in the 27th century afterwards, the cycle repeats (itself). In the circle of the nakshatras, wherein the seven Rishis revolve, and which contains 27 in its circumference, the seven Rishis remain 106 years in each in turn. This is the cycle of the seven Rishis, remembered according to divine reckoning² as 6 divine months and 7 divine years."³

¹ Cf. Aetius, ii, 23, 1: "The stars execute their turnings in consequence of their being driven out of their course by condensed air which resists their free motion." Quoted by HEATH, *Aristarchus of Samos*, p. 42. Aristotle, also speaks of the winds as causing the heavenly motions. (ib. p. 33.)

² A divine year is 360 ordinary years.

³ No satisfactory explanation of this passage has yet been given. If the nakshatra scale were a relative scale like the western zodiac, then the revolution of the constellation might be accounted for by precession. The difficulty lies in the period of 2,700 years: the actual period of precession is about 25,696 years while the later Hindu texts give 24,000 years. Al-Bīrūnī (*India* xlv) questions the figures and attributes to Varāha Mihira the statement that the Great Bear remains 600 years in each nakshatra. Now $600 \times 27 = 16,200$ and does not help us (but $600 \times 27 = 24,300$ would). The text however gives 2,700 in three distinct forms and can hardly be questioned. A possible explanation is in connection with the inaccurate length of the year in use. Suppose, for example, it was known that the orthodox elements were wrong, and that the error in the length of the year was estimated to be about one day in a cycle of eight years. A reconciliation could then be achieved by making the constellations revolve once in about 3000 years. Cf. COLEBROOKE *Essays* ii, 355 f.; JAOS 1858, p. 364; ALLEN, i, 389 f.; *Bṛhat Saṃhitā*. Ch. xiii. BRENNAN's *Hindu Astronomy* Ch. V. should be read.

CHAPTER IV.

Early formal astronomy.

23. Of the chronology of the period marked A2 in the scheme given in paragraph 8 above we know practically nothing except the epoch of *Paitāmaha Siddhānta*, which is definitely fixed at 2 Śaka or A.D. 80. The other texts usually attributed to this period are the *Jyotisha Vedāṅga*, the *Sūryaprajñapti*, and, we may add, certain sections of the *Kauṣilya Arthaśāstra*.

The main astronomical features of these works are (a) the five-year cycle of 5×366 days, (b) the omission of all reference to planetary phenomena.

The *Jyotisha Vedāṅga*¹ employs a cycle of five years of 5×366 sāvana or civil days, 5×367 sidereal days, 61 months of 30 sāvana days each, 62 synodic months and 67 sidereal months. The number of risings of the moon is given as $5 \times 366 - 62 = 1768$ and the moon crosses the ecliptic 134 ($= 2 \times 62 + 2 \times 5$) times. A so-called 'solar day' appears to be referred to.

The sidereal day dropped out of use in later Hindu works; the lunar day based on the analogy of the solar day and counted from moonrise to moonrise does not appear ever to have been used in practice, and was later on superseded by the tithi, of which there were 30 to the synodic month. The tithi is not defined in the *Jyotisha Vedāṅga* but it is implied and its length was $(1 - \frac{1}{60})$ of a sāvana day. The elements given and implied are here summarised.

JYOTISHA VEDĀṅGA ELEMENTS.

$5 \times 366 = 1830$ sāvana or civil days = 61 months of 30 sāvana days each. $5 \times 367 = 1835$ sidereal days = 67 sidereal months of $27\frac{2}{3}$ sāvana days each $5 \times 366 - 62 = 1768$ lunar days $5 \times 372 = 1860$ tithis = 62 synodic months of 30 tithis each.		} = 5 years.
1 solar day = $1 + \frac{1}{40}$ sāvana days.	1 sāvana day = $1 - \frac{1}{40}$ solar days.	
1 tithi = $1 - \frac{1}{60}$ " "	1 " " = $1 + \frac{1}{60}$ tithis.	
1 sidereal day = $1 - \frac{1}{360}$ " "	1 " " = $1 + \frac{1}{360}$ sidereal days.	
1 year = 366 sāvana days = 372 tithis = 367 sidereal days = 360 solar days.		
1 synodic month = $29\frac{1}{2}$ sāvana days = 30 tithis.	1 sidereal month = $27\frac{2}{3}$ sāvana days.	

The cycle of five years began at the winter solstice with the new moon in Śravishṭhā. The identification of Śravishṭhā is uncertain but modern books give the small group of stars β, α, γ, δ, Delphini, and the winter solstice occurred there about 1400 B.C. But the year of 366 days is so inaccurate that the error of position calculated according to the *Jyotisha Vedāṅga* would in some 600 years amount to 360 degrees. Thus the effects of precession were completely masked and it is not surprising that there is no reference to that phenomenon.

¹ See A. WEBER *Über den Veda Kalender*; G. THIBAUT *Jour. As. Soc., Bengal*, 1877; pp. 411—437; LALA CHHOTK LAL *The obscure text of the Jyotisha Vedāṅga explained*.

The calculations given for the positions of the solstices are even more erroneous still. It is indeed probable that the winter solstice referred to was a nominal one, like the vernal equinox still employed in India.

The chief characteristic of the *Jyotisha Vedāṅga* appears to be what may be termed the zodiacal calculations. The 27 nakshatras each occupy the same space, namely $13\frac{1}{2}$ degrees¹; but the positions of these nakshatras relative to the stars is nowhere defined, and consequently the initial point of the ecliptic is completely unknown. There is a suspicion that the nakshatras scheme was employed like the western zodiac as a relative scale of measurement only and not as a definitely fixed scale. The principal parts of the text are concerned with calculation of the motions of the sun and moon relative to this scale and the positions of the moon in it at the solstices and at new and full moon. For example: The sun remains in a nakshatra $\frac{1830}{5 \times 27} = 13\frac{2}{3}$ days, and the moon remains in a nakshatra $\frac{183}{27 \times 67} = 1\frac{1}{3}$ days. Also since there are 186 lunar days in one ayana and since $186 = 6 \bmod. 30$, successive solstices will occur on the 1st, 7th, 13th, 19th and 25th lunar days. Also the moon traverses 27×67 nakshatras in 10 ayanas or $\frac{1809}{10} p = p(6 \times 27 + 18\frac{3}{10})$ nakshatras in p ayanas. We may neglect the whole revolutions and $p(18\frac{3}{10})$ will give the position of the moon, and making $p = 1, 2, 3$, etc., we get the successive positions as $18\frac{3}{10}, 37\frac{6}{10}, 56\frac{9}{10}, 75\frac{12}{10}, 94\frac{15}{10}, 113\frac{18}{10}, 132\frac{21}{10}, 170\frac{1}{10}$ or, after subtracting multiples of 27, $18\frac{3}{10}, 10\frac{8}{10}, 2\frac{1}{10}, 21\frac{6}{10}, 13\frac{5}{10}, 5\frac{4}{10}, 24\frac{3}{10}, 16\frac{2}{10}, 8\frac{1}{10}$ and the nakshatras in which the moon will be at successive solstices are the 19th, 11th, 3rd, 22nd, 14th, 6th, 25th, 17th, and 9th counting from Śravishthā.

The results actually given in the text may be tabulated thus:—

Winter solstice.	POSITION OF THE MOON.		Summer solstice.	POSITION OF THE MOON.	
	Nakshatra.	Its No.		Nakshatra.	Its No.
1	At beginning of Śravishthā	i	2	Chitrā	xix
3	Ārdra	xi	4	P. Bhādrapadā . . .	iii
5	Anurādhā	xxii	6	Āśleshā	xiv
7	Āsvini	vi	8	P. Ashādhā	xxv
9	U. Phalguni	xvii	10	Rohiṇi	ix

New and full moon.—Next is given a very curious (and very inaccurate) table showing the position in each nakshatra at which a new or full moon takes place. Each nakshatra is divided into 124 aṁśas or parts and the results are tabulated, not in order of occurrence but, in the order of position within the nakshatras, thus:—

Aṁśas . . .	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Nakshatras . .	i	vi	xi	xvi	xxi	xxvi	li	ix	xiv	xix	xxiv	li	vi	xi	xvi	xxi	xxvi	v	x	xi	xv	xx	xxv	li	vi	xi	xxii	i

¹ Note, however, that the unit of measurement is the nakshatra and not the degree. The nakshatra was divided into 124 aṁśas or parts, each aṁśa thus being equivalent to 3.5 minutes of arc.

where *i* stands for Śravishthā¹, *vi* for Aśvini and so on in order. Although it is not so stated the full moons occur at the odd numbers of amśas and the new moons at the even numbers; and the table means, for example, that when a new moon occurs in the *x*th nakshatra (i.e., Mṛigaśiras) it will be at the 18th amśa or division. The rationale is as follows: Since in the five-year cycle the moon is in syzygy 2×62 times, and since during that period it traverses 27×67 nakshatras, we have $\frac{27 \times 67}{2 \times 62} = 14\frac{73}{124}$ nakshatras between each syzygy or parvan, and for the *x*th parvan the position of the moon is given by $14x + 73x/124 = y$. Solving $73x = n \bmod 124$ we get $n = 0, 1, 2, 3, 4$ for $x = 0, 17, 34, 51, 68$, or $x = 17n$. Therefore $y = n \times 9 \times 27 + n (5\frac{1}{124})$ and $5n + 1$ is the nakshatra in which the moon lies when the amśas are *n*.

Length of day.—The length of day *l* is given by the rule $l = 12 \pm 2(183 - n)/61$ where *n* is the number of days counting from a solstice. The longest day is therefore 18 muhūrtas = 14 hours 24 minutes, the shortest day is 12 muhūrtas = 9 hours 36 minutes and the daily increment is $\frac{3}{61}$ muhūrtas = 1 minute 34.4 seconds. Time was measured by a clepsydra of which one prastha was equivalent to the daily increment.

JAINA ASTRONOMY. THE SŪRYAPRAJŪPTI.

24. The principal source of information about the Jaina astronomical text known as the *Sūryaprajñapti* is Malayagiri's commentary, and this has been expounded briefly by Weber² and more fully by Thibaut.³ The *Sūryaprajñapti* is, from the astronomical point of view, of much the same type as the *Jyotiṣha Vedāṅga*, but, possibly, it is of a later period.

Popularly the most marked feature of the system set forth in the *Sūryaprajñapti* is the somewhat strange cosmography that appears to have been peculiar to Jaina teaching. As in the Purāṇas, Mount Meru is placed at the centre of the earth, and round Meru are seven concentric annuli. Of these the innermost, Jambū-dvīpa, is divided into four quarters of which the southernmost is Bharata-varsha (India). The heavenly bodies move parallel to the surface of the earth, with the centres of their orbits at Meru, which intercepts their light⁴. This scheme presents certain difficulties in explaining the alternation of day and night, etc. These difficulties the Jainas tried to overcome by assuming two similar but opposite suns, two moons, two sets of stars, etc.⁵ This duplication of the heavenly bodies was animadverted upon by later Hindu writers, but the absurdity lies in the assumption, common to all Hindu teaching of the period, of Mount Meru, the four quarters of the world, etc.

¹ For a list of the nakshatras, see appendix iii, p. 118.

² *Ind. Stud.* 1867, x, 254 f.

³ *JASB* 1880, 107 f. and 181 f.

⁴ Compare ARISTOTLE (Met. ii, 1354 a 28) who says: "Many of the ancient meteorologists were persuaded that the sun is not carried under the earth, but round the earth, and in particular our northern portion of it, and that it disappears and produces night because the earth is lofty toward the north." (T. L. HEATH *Aristarchus of Samos*, p. 41.)

Aetius writes: "Xenophanes says there are many suns and moons according to the regions, divisions and zones of the earth." HEATH, p. 56. The early Christian writers exhibit far more absurd cosmological notions.

The astronomical elements of the *Sūryaprajñapti* may be summarised as follows :—

The cycle of 5 years consist of	The year consists of	The months are
1830 sāvana days . . .	366 sāvana days . . .	solar month = $30\frac{1}{2}$ sāvana days.
1860 tithis . . .	367 sidereal days . . .	sāvana month = 30 sāvana days.
1800 solar days . . .	360 solar days . . .	synodic month = $30 \times (1 - \frac{1}{81})$ sāvana days.
60 solar months . . .	12 solar months . . .	sidereal month = $27\frac{1}{2}$ sāvana days.
		The days are
61 sāvana months . . .	12 sāvana months . . .	solar days = $(1 + \frac{1}{81})$ sāvana days.
62 synodic months . . .	12 or 13 synodic months . . .	tithi = $(1 - \frac{1}{81})$ sāvana days.
67 sidereal months . . .	2 ayanas of 183 days each . . .	sidereal day = $(1 - \frac{1}{81})$ sāvana days.

The cycle is also divided into five lunar years of which the first, second and fourth consist of 12, and the 3rd and 5th of 13 synodic months. The synodic month is also divided into two lunar *ayanās* and six lunar seasons.

The cycle commences at the summer solstice when the moon is full at the beginning of Abhijit and thus differs from the *Jyotisha Vedāṅga* scheme. Thibaut argues¹ that the *Sūryaprajñapti* scheme is a modification of that of the *Jyotisha Vedāṅga*, due to observation, and the change is due to the solstices having moved through $17\frac{1}{2}$ degrees, the space occupied by Śravaṇa and Abhijit. A precession of this amount is equivalent to about 1250 years; but Thibaut rightly cautions his readers about the soundness of this deduction, which is extremely doubtful, owing to the general ambiguity of the texts, and, in particular, owing to the difference in the scales employed (to be shortly explained), to the crudeness of the observations and to the very great errors in the elements employed. If Abhijit is to be identified with α Lyrae, as it invariably has been, then the date of observation must have been about A.D. 850, when the winter solstice took place at the same longitude as α Lyrae.

The ecliptic is divided into 28 unequal divisions to which the names of the nakshatras beginning with Abhijit, are given. The scale is connected with the sidereal month, which was $\frac{1860}{67} = 27\frac{1}{2}$ sāvana days, the whole circle of the ecliptic being divided into $27\frac{1}{2}$ parts², allotted as follows :—

Nakshatras	i	ii	iii	iv	v	vi	vii	viii	ix	x	xi	xii	xiii	xiv	xv	xvi	xvii	xviii	xix	xx	xxi	xxii	xxiii	xxiv	xxv	xxvi	xxvii	xxviii	TOTAL
Timespaces	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	

¹ JASB, 1880, p. 117.

² After the fashion of the time measures of Hypsicles.

Each time space unit is equivalent to $13\frac{1}{2}$ degrees. The scale is very different from that of the *Jyotisha Vedāṅga* and as in neither system is the position of the initial point defined it is almost impossible to compare any of the statements made with reference to the two systems.

The sun revolves round Mount Meru always at the same height from the plane of the earth, namely 800 yojanas, but at varying distances from Mount Meru.¹ The radius on the longest day is 49,820 yojanas and on the shortest day it is 50,330 yojanas, the daily increase being $\frac{510}{183} = 2\frac{4}{11}$ yojanas. The longest day is, as in the *Jyotisha Vedāṅga*, 18 muhūrtas (=14·4 hours), and the shortest 12 muhūrtas (=9·6 hours), and the daily change $\frac{1}{6}$ muhūrtas (=1·57 minutes), and the corresponding latitude would be about 36 degrees.

To overcome the difficulty of explaining the rising and setting of the sun it is assumed that that body becomes visible only when he is within a distance equal to half the extent of his day's journey.

The moon is also supposed to move in concentric circles round Meru at a distance of 880 yojanas from the plane of the earth, that is 80 yojanas further away than the sun. It enters into conjunction with the sun $1830 - 1768 = 62$ times and completes 67 sidereal revolutions in the five years.

The ecliptic is divided (as already explained) into $\frac{1830}{67}$ sāva_{1,4} day spaces or $\frac{1830 \times 20}{67}$ muhūrta spaces and consequently the sun moves through $66 + \frac{1}{2} + \frac{1}{62 \times 67}$ muhūrta spaces in one synodic month.²

The positions of successive solstices are given in tithis as in the *Jyotisha Vedāṅga*. Since $186 = 6 \bmod 30$ the successive solstices will occur on the 1st, 7th, 13th, 19th, 25th tithis.

It is just mentioned—no details being given—that the planets travel faster than the sun and the stars, and the stars faster than the nakshatras. Thibaut says³ that the latter statement is entirely indefensible and that no reason leading to it can well be imagined; but there is a possible explanation, namely that the nakshatras were considered as a scale fixed with reference to the equinoxes, exactly in the same manner as the zodiac is now considered, and that the stars precessed with reference to the equinoxes.

¹ For a revival of this notion see A. DE MORGAN *A Budget of Paradoxes* ii, p. 90 (2nd edition).

² In 62 synodic months the sun traverses the whole ecliptic 5 times and $\frac{1}{62}$ of $\frac{1830 \times 20}{67} = \frac{1}{62}$ of 4097 $\frac{1}{2}$, = 66 + $\frac{1}{2}$ + $\frac{1}{62 \times 67}$.

³ JASB, 1880, p. 185.



CHAPTER V.

Special topics.

25. In the present chapter it is proposed to collect and arrange the material relating to the several special questions that have arisen. This will lead to a certain amount of overlapping, which, however, cannot well be avoided, and is not altogether objectionable.

The topics of particular interest that will be discussed are (a) the ecliptic scale of 27 or 28 nakshatras, (b) stars and constellations proper, (c) the year, cycles, equinoxes, solstices, (d) precession, (e) the months and seasons, (f) the planets, particularly with reference to their late appearance in Hindu works, (g) the demons of eclipses—Rāhu and Ketu, (h) the planetary week days, (i) heliacal risings and settings of stars, (j) the cycle of Jupiter, (k) Mount Meru. Of these topics some (f, g, h, i, j) perhaps do not strictly belong to the early period (A) of Hindu astronomy, although certain writers include them into that period. This section therefore forms a sort of connecting link between the periods we have designated A and B (§ 8).

26. NAKSHATRAS.—The early records appear to indicate that the ecliptic was roughly plotted out, in a manner analogous to the western zodiac, into 27 or 28 groups of stars called nakshatras. These have sometimes been termed 'lunar asterisms' or 'lunar mansions,' and, although the term nakshatra does not itself suggest this connexion, the *Black Yajur Veda* (KS¹ xi, 3 and TS ii, 3, 5) and the *Mahābhārata* (ix, 35⁴⁵) state that the nakshatras were wedded to Soma. The *Rig-Veda* gives no complete list of the nakshatras but it mentions three probable asterisms—Tishya (v, 54¹³; x, 64⁸), Aghās and Arjunī (x, 85³); and it has been suggested that there is a reference to the 27 nakshatras in i, 162¹⁸. Lists are given in the *Atharva Veda* (xix, 7), the *Taittirīya Samhitā* (iv 4, 10), the *Kaṭha Samhitā* (xxxix, 13), the *Maitrāyaṇī Samhitā* (ii, 13²⁰), the *Śatapatha Brāhmaṇa* (x, 5, 4⁵), etc., etc. The lists agree generally but the number of nakshatras is variously given as 27 and 28. The *Atharva Veda* and *Maitrāyaṇīya Samhitā* lists have 28, while the *Taittirīya Samhitā* and the *Śatapatha Brāhmaṇa*, etc., give 27. Of the more modern texts the *Jyotisha Vedāṅga* and the *Sūrya Siddhānta* (ii, 64) imply 27, while the *Sūryaprajñapti*, the *Brāhmasphuṭasiddhānta* and the *Sūrya Siddhānta* (viii, 1 f.) imply 28. Whether 27 or 28 was the original number is uncertain. Abhijit is the extra nakshatra and there is a legend that it dropped out (MB iii, 230¹¹) although the *Taittirīya Brāhmaṇa* (i, 5, 2³) marks it as a new-comer. The numbers 27 and 28 suggest a connexion with the sidereal month, but in the early texts the only month referred to is one of 30 days and even in the later works the synodical month is divided into 30 tithis. The Arabic Manāzil and the Chinese Sieou consist of 28 asterisms and the Chaldean scheme has the same number; and the con-

¹ For explanations of the abbreviations employed see page 127.

nexion between these systems and the Hindu nakshatras has been the subject of much discussion.¹

No satisfactory explanation of the different numbers has been achieved; Weber thought 27 was the older number but the authors of the *Vedic Index* suggest that Abhijit was omitted and that the number $27=3^3$ appealed as being of a more mystical nature.² In the lists of nakshatras it will be noticed (see appendix iii) that there are not 27 or 28 different names but only 24 or 25. The former number is suggestive and seems to indicate the possibility of a division into 24 half signs (*horā*, cf. *parvan*), and this is to some extent supported by the connexion between the names of the months and the nakshatras³.

The positions of the nakshatras in the heavens are not defined at all in any of the early texts. Even up to the time of Varāha Mihira (6th century A.D.) nothing adequate is given in this direction: the *Pañchasiddhāntikā* gives the *yogatārās* of seven asterisms only and their positions are indicated in a very crude manner and with little attempt at accuracy (see section 63); indeed the identifications with certain stars or constellations are all comparatively modern, and, apparently the nakshatras never were completely so identified by Hindu astronomers. About A.D. 1000, however, the initial point of the Hindu sphere was marked by the principal star of the nakshatra Revati which was identified with ζ Piscium, or, by some authorities, the initial point was placed ten degrees west of ζ Piscium.

Although in the early texts there are many cases in which the positions of the sun and moon are defined by reference to the nakshatras, e.g., 'the full moon in Phalgunī,' etc., yet there is nothing that defines the nakshatra scale earlier than the *Jyotisha Vedāṅga*, which divides the ecliptic into 27 equal nakshatras and marks the winter solstice by Śravishṭhā (see § 23). The *Sūryaprajñapti* divides the ecliptic, on the basis of the sidereal month, into $27\frac{2}{3}$ equal parts giving half a part to each of six nakshatras, a whole part to each of fifteen, one and a half to each of six, and the remaining $\frac{2}{3}$ to Abhijit, while the sun in Abhijit marks the winter solstice. At some period or other the names of the months and the names of the nakshatras were made to correspond to a certain extent (see § 29).

None of these scales definitely suggests that the nakshatras were constellations: rather, on the other hand, they do suggest that the nakshatra scale was like the western zodiac, a sort of sliding scale* of which the zero point was an equinox (or solstice). This possibility of the nakshatras being the names of divisions of the ecliptic and of their not being connected with any particular constellations has, apparently,

¹ See SIR W. JONES *Works* iv, 71; H. T. COLEBROOKE *Essays* ii, 321; A. WEBER *Ind. Stud.* ix p.424; x, 213, etc.; G. D. WHITNEY *Studies* ii, 341; JAOS vi, 1858, p. 467 f; and viii, etc.; J.B. BIOT *Astronomie ancienne*, etc., etc.; G. THIBAUT JASB lxiii; etc., etc.

² A passage in the Śatapatha Brāhmaṇa (x, 5, 4*) that refers to 756 altar bricks has been described as a piece of priestly nonsense, but it is rather curious that $756=27 \times 28$.

³ See ALBERTONI (*India* i, 358), who was inclined to think that the Hindus had divided the ecliptic into six parts.

*There is evidence, however, that the equinoxes and solstices were thought to be absolutely fixed and that the constellations moved (see § 62).

not yet been considered, but it is rather attractive. In Greek astronomy the zodiac names, presumably, did originally refer to particular constellations, but later they were used as a measure of the ecliptic (reckoning from the vernal equinox). Owing to the precession of the equinoxes the names of the signs no longer have any real connexion with the constellations: Aries occupies the 30 degrees of the ecliptic east of the vernal equinox. Taurus the next 30 degrees, and so on.* There is other weighty evidence in support of the 'sliding scale' hypothesis. For example (a) According to the *Śatapatha Brāhmaṇa* (ii, 1, 2⁴) Kṛittikā never moves from the east, i.e., it marked the junction of the ecliptic and equator quite independently of any constellation, (b) the *Sūryaprajñapti* tells us that the stars move faster than the nakshatras, (c) the Purāṇas all record that the constellation of the seven Rishis gradually revolves through the nakshatras.†

The early lists of the nakshatras all begin with Kṛittikā, which, if equivalent to the Pleiades, marked the vernal equinox about 2300 B.C. The *Jyotiṣa Vedāṅga* puts Śravishṭhā first, while the *Mahābhārata* substitutes Śravaṇa, the *Sūrya Siddhānta* gives Aśvinī first while the *Sūryaprajñapti* begins with Abhijit. These form two groups—Kṛittikā to Aśvinī and Śravishṭhā to Abhijit, separated by about one quarter of the ecliptic (see the list in appendix iii).

The change from Kṛittikā to Aśvinī seems at first to be an astronomical one inspired by a knowledge of the effects of precession, but there are grave objections to this explanation (see § 31) and Tilak and Fleet suggest that the original order was either a ritualistic or an astrological order. According to Tilak it is stated by Garga that Kṛittikā was first for purpose of ritual and that for the calendar Śravishṭhā was first; while Fleet in one of his latest papers‡ wrote—"I hope to revert to this matter in a paper in which I shall show that the Kṛittikādi list has no basis in the fact that the sun once came to the vernal equinox in Kṛittikā, but belongs entirely to ritual and astrology."

Another possible explanation lies in the various practices in different parts of India regarding the commencement of the year (see § 32).

STARS AND CONSTELLATIONS.

27. It is very noticeable that the nakshatra names in the early works are nowhere definitely connected with particular stars or constellations. It is only in comparatively very modern texts that such a connexion is given and even in quite modern times the identifications are often doubtful. Albīrūnī said that he could find no Hindu astronomer to identify them all, and so did Sir William Jones and H. T. Colebrooke. Of stars and constellations actually or probably mentioned as such the following is a fairly complete list.

*The Hindus, it may be noted, make a further abstraction still and employ the term Aries to denote any arc of 30 degrees, Taurus to denote 60 degrees, and so on.

† The nakshatra Puruṣa as given in the *Bṛhat Saṃhitā* (LVIII, 105) cannot be made to fit the constellations. It is probably based upon the Kāla Puruṣa (BJ i, 4) a human figure made up of all the signs of the zodiac.

‡ JRAS 1916, p. 570. Dr. J. F. Fleet, to whose kindness and scholarship so many of us are indebted, died in February 1917. It is to be hoped that his thesis will be made available, although it could hardly eliminate the desire for an astronomical explanation of the Kṛittikādi list.

DHRUVA, the Pole Star, appears late.¹ Jacobi identifies it with α Draconis and thinks it was actually observed about 2780 B.C. The Maitrāyaṇa-brāhmaṇa Upanishad speaks of 'the moving of Dhruva' as inconceivable.

THE SEVEN RISHIS,² are usually identified with Ursa Major. They were the husbands of the seven Kṛttikās and they rose in the north. The Purāṇas relate, and it is repeated by Varāha Mihira (BS xiii), that the seven Rishis were in Maghā 2536 years before the Śaka era, and that they remain in each asterism 100 years. The names of the seven Rishis are given in BS. xiii but appear to have no astronomical significance.

THE KṚTTIKĀS are generally identified with the Pleiades. They are usually seven and are the wives of the seven Rishis. Their names are⁴ Ambā ('a mother'), Dalā, Nitatnī, Abhṛayanti ('forming clouds'), Meghayanti ('making cloudy'), Varshayanti ('causing rain'). The rain producing function appears to have been rejected later (e.g., by Varāha Mihira, BS xxi, 5). The Kṛttikās are said to rise in the east and not to move from the eastern quarter.⁵

ROHINĪ⁶ is identified with Aldebaran, (α Tauri), but the term means 'red' and is also applied to the nakshatra Jyeshthā. Prajāpati (Orion) pursued his daughter (Rohinī) and was shot by Mṛiga Vyadha (Sirius) with the arrow (Ishu Trikāṇḍa=Orion's belt). The myth was, in the Greek fashion, put into a star picture. According to western legend Orion was a hunter, who, with his dog Sirius, pursued the Pleiades, or was pursued by the bear and killed by the scorpion. Another Rohinī myth, where she is the favourite wife of the moon, is given in MB. ix. 35. This seems to be the basis of chapter xxiv of the *Bṛihat Saṃhitā*. (See also appendix ii.)

MṚIGA.—Mṛiga denotes 'animal' and in the Rohinī legend is identified with Prajāpati and the legend is obviously connected with the Greek story about Orion. Tilak however, makes a special constellation of Mṛiga consisting of (as far his description is understood) β , α , ζ , ϵ and δ Orionis.

MṚGAVYĀDHA, 'the hunter', is Sirius in the Rohinī legend.

DIVYA ŚVAN, 'the divine dog', may in AV. vi. 80 denote Sirius.

The three KĀLAKAṆJAS are mentioned only in the same passage with Divya Śvan (AV. vi. 80) and may refer to ζ , ϵ , δ Orionis.

TISHYA may refer to a star or constellation. There are two interesting references in the Rig-Veda: The first speaks of Tishya vanishing from the sky: the second enumerates with Tishya 21 rivers, floods, mountains Agni, Kṛishānu and Rudra—28 items in all. Fleet identifies Tishya with Præsepe, others suggest Sirius.

ARUNDHATĪ is an unidentified star often referred to in Sūtra literature. TRISAṆKU as a constellation shines 'head downward' but is also unidentified.¹³

¹ AGS-I, 722; ŚGS-I, 172; LSS-III, 34; MBU-I, 4; R-VI⁴.

² RN-x, 822; AV-vi, 401; ŚB-II, 1, 24; ŚB-III, 8, 12; MB-V, 110.

³ ŚB-II, 1, 24; etc.

⁴ TS-iv, 4, 51; TB 1, 41; etc. (For the meanings of the abbreviations here employed see page 127.)

⁵ ŚB-II, 1, 24.

⁶ TS-II, 34; AB-III, 33; ŚB-II, 1, 24.

⁷ TS-II, 34; MB-ix, 35; R-I, 1; R-II, 16 114 118; R-III, 46; R-V, 33, etc.; BS-XXIV.

⁸ AB-III, 33.

⁹ Orion, p. 96.

¹⁰ AB-III, 33.

¹¹ RV-v, 5412; RV-x, 642.

¹² JRAS, 1911, p. 514 f; see also TB-III, 1, 12.

¹³ Rāmāyaṇa LX is devoted to Trisaṅku's translation. See also VP-iv, 3, etc. The 'Southern Cross' has been suggested.

Of later works the *Sūrya Siddhānta* mentions only seven stars besides the nakshatras, namely Brahmahridaya (α Aurigæ), Agni or Hutabhuj (ρ Tauri) Prajāpati or Brahma (δ Aurigæ), Mrigavyādhā or Lubdhaka (Sirius), Agastya (Canopus), Apas (θ Virginis) and Apamvasta (δ Virginis).

28. THE YEAR.—The only year clearly referred to in the Rig-Veda is one of 360 days and 12 months. Attempts have been made to discover references to years of other lengths but not with success. Neither is any cycle definitely mentioned.¹ There is, however, a reference to a thirteenth month of 30 days in the Atharva Veda and in the Brāhmaṇas a thirteenth month of 35 or 36 days is mentioned. In the Mahābhārata is a bare mention of a 5-year cycle, which remained in use until A.D. 80 and, possibly, to a considerably later period. By A.D. 505 larger cycles had come into use, and finally the cycle of 4,320,000 was permanently adopted. The following table summarises the main facts:—

Rig-Veda	360 days and 12 months. A possible reference to a thirteenth month.
Atharvaveda	A thirteenth month of 30 days.
Brāhmaṇas	A thirteenth month of 35 days, and one of 36 days.
Mahābhārata	A 5-year cycle is mentioned.
Jyotisha Vedāṅga, Paitāmaha Siddh.	} A 5-year cycle of 1830 days.
Sūryaprajñapti, Kautilya's Arthaśāstra	
Romaka Siddhānta	A cycle of 2,850 years, or 1,040,593 days; which reduces to 19 years and 6,939 days. (Cf. the Metonic cycle of 19 years and 6,940 days).
Sūrya Siddhānta i. (circa A.D. 500)	A cycle of 180,000 years or 65,746,575 days.
Sūrya Siddhānta ii (circa A.D. 1000)	A cycle of 1,080,000 years or 394,479,457 days.
Ditto ditto	A cycle of 4,320,000 years, or 1,577,917,828 days. ²

29. MONTHS AND SEASONS.—We have two sets of names for the months, neither of which is very early—

	Months.	Seasons.
Ūrja	Kārttika (October-November)	Śarad (Autumn).
Saha	Mārgaśīrsha (November-December)	} Hemanta (Winter).
Sahasya	Pausha (December-January)	
Tapa	Māgha (January-February)	} Śīsira (Dewy season).
Tapasya	Phālguna (February-March)	
Madhu	Chaitra (March-April)	} Vasanta (Spring).
Mādhava	Vaiśākha (April-May)	
Śukra	Jyaiṣṭha (May-June)	} Grishma (Summer).
Śuchi	Āshādhā (June-July)	
Nabha	Śrāvaṇa (July-August)	} Varsha (Rains).
Nabhasya	Bhādrapada (August-September)	
Isha ¹	Āśvina (September-October)	Śarad (Autumn).

¹ Weber states that "the earliest allusion to the quinquennial yuga occurs in the Rik itself, i, 25⁴." (*History of Indian Literature*, p. 113). The passage in question is: "He, who accepting the rites, knows the twelve months and their production, and that which is produced in addition." At the best Weber's statement is a very doubtful deduction; but see also R. Shamasastry's *Gaṇam Ayana*, to which reference is made in § 32.

² See also appendix iii, 4.

³ Ūrja and Isha are, more or less, synonymous.

The first list, which is possibly the older, is obviously not a list of twelve months but of six seasons adapted. The second method of naming is only beginning to be used in the Brāhmaṇas but is regularly employed in the Mahābhārata. It consists of the names of twelve of the nakshatras and it is usually explained that the month was originally named after the nakshatra with which the moon was in conjunction at the end of the parvan, or half month (SS. xiv).¹ In the earlier period the seasons appear to have been three in number, and later grew to five or six; and even seven are mentioned (AV. vi. 61; ŚB. vii. 5-1, etc.) in the post-Vedic times six was the number generally accepted.

30. SOLSTICES AND EQUINOXES.—In the Rig Veda (X. 27; X. 98¹¹) the 'way of the fathers' (*Pitriyāna*) is mentioned in contradistinction with the 'way of the gods' (*Devayāna*); and in the *Śatapatha Brāhmaṇa* (ii. 1, 3) we read—"The spring, the summer and the rains—these seasons the gods; and the autumn, the winter and the dewy season represent the fathers.... Now when he (the sun) moves northwards, then he is among the gods, then he guards the gods; and when he moves southwards then he is among the fathers, then he guards the fathers." Tilak concluded² that the *Pitriyāna* and *Devayāna* of the earlier texts might be equated with the *Dakṣiṇāyana* and *Uttarāyana* of the later texts; and that the *Uttarāyana* or 'northern progress' began with the vernal equinox. But the astronomical conception of the two portions of the sun's path is comparatively late and the orthodox view certainly was that the solstices divided the two portions—the *uttarāyana* or 'progress northwards' and the *dakṣiṇāyana* or 'progress southwards.' The *Pañchasiddhāntikā* says (iii. 25) "The northern progress of the sun begins with the first point of Capricorn," and this is the natural interpretation of the term *uttarāyana*.

The term for equinox used in modern works is *vishuvat*, which may be rendered 'point of equal separation.' Although Haug translates the term, *vishuvat* by 'equator' he is possibly wrong;* for the term, as an astronomical one does not appear in Hindu works before the Greek period. Indeed, with an astronomical meaning, the equinoxes, even for the later Hindu astronomers denoted only the time when days and nights were equal. The idea of the equinoxes marking the intersection of the ecliptic and equator is not explicitly referred to; and the notion of a celestial equator is nowhere clearly exhibited.

In the *Jyotiṣa Vedāṅga* the rules for calculating the positions and times of occurrence of the solstices state that they recur in order on the 1st, 7th, 13th, 19th, and 25th lunar day and that the nakshatras in which the moon will be at successive solstices are the 19th, 11th, 3rd, 22nd, 14th, 6th, 25th, 17th, and 9th; and these results are based upon an interval of 183 days between successive solstices.

¹ It is possible that the nakshatras were named after the months.

² *Orion*, p. 24.

* AB iv. 18: See also AB, iv 22 and TS vii 4*.

31. PRECESSION.—Observation of the change in the positions of the equinoxes or solstices relative to the fixed stars requires a series of fairly accurate records spread over a considerable period of time. It implies a fairly accurate knowledge of the length of the year and eventually it leads to the differentiation between the tropical and sidereal year. The actual amount of the precession in longitude is about 50.26 seconds of arc a year, or, put in another way, the difference between the sidereal and tropical year is a little over 20 minutes of time; and the first requirement for its observation is that the length of the year must be known with an accuracy of the same order (i.e., the error in the length of the year should be less than 20 minutes). Hipparchus' value of the length of the year was only a little over 6 minutes too long, but the Hindu year, before the advent of Greek teaching, was over 17 hours too long, and it was therefore practically impossible for them to note the precession of the equinoxes. Further, the positions of the solstices (and equinoxes) were, according to their calculations, even more erroneous than their length of the year; and they, apparently, neither recorded nor observed the positions of any star with any exactitude, and even in modern times they did not differentiate clearly between the tropical and sidereal year.

Such considerations seem to preclude any possibility of a knowledge of precession by the early Hindu astronomers; and, it may be added, that if they had such knowledge, they apparently thought it of altogether subordinate interest and importance.

But there is a type of astronomical record altogether different from that we have been considering, the type that is not a record of direct observation or calculation, but is rather a reflection or echo of teaching in other countries or in earlier times. The discovery of precession has generally been attributed to Hipparchus (circa 130 B.C.), but the opinion now seems common that the Babylonians had a clear conception of it long before his time. According to Jeremias¹ the Babylonians calendar was periodically rearranged with reference to the position of the vernal equinox. The ages of the Twins, the Bull and the Ram thus corresponded with the vernal equinox in those constellations. If this is the correct interpretation of the evidence (I doubt it) then we should not be surprised to find some reflection of the same phenomena in Hindu works. A list of references to passages that might bear some such interpretation is given below (§ 32). In that list are three columns referring to (A) the solstices or equinoxes, (B) the nakshatras, and (C) the fixed stars. In the early cases (a to f) the solstice or equinox is nowhere defined, and in most of these cases the equation of A with B is quite illegitimate; neither is the equation of B with C certain in any case, and it is even possible that the nakshatra scale had really no definite reference to particular fixed stars. The equations of

¹ ERE i, 183 f. But Tannery thought that the Chaldeans had knowledge neither of the tropical year nor of the precession of the equinoxes. Heath also appears to think that the early Babylonians were not acquainted with precession (*Aristarchus of Samos*, p. 105). It may also be noted that precession was denied by Proclus who invoked Plato, the Chaldeans, the Egyptians and the gods in support of his view. BOUCHÉ LECLERCQ *L'Astrologie grecque*, pp. 24, 115, 574.

A, B and C therefore become a matter of extreme doubt and the chances of a correct conclusion being achieved by such equations infinitesimally small. In the examples *h* to *m* the solstices are definitely referred to but in these particular cases the year employed is far too inaccurate to permit of deductions regarding precession, and the solstices are given as 183 days apart, and the only records of this period of star positions are also far too inaccurate to be of use for this purpose.

Nevertheless there appear to be unmistakable indications of some knowledge of precession. This knowledge may have been vague—it certainly did not affect in any way the astronomical schemes devised—and it is possible that the evidence is merely a shadowy reference to a point of exotic teaching that was not fully comprehended. The evidence is of different types, *e.g.*—

- (a) The five-year cycle is said to begin with the winter solstice in Śravishthā or Abhijit or the summer solstice in Punarvasa. (See § 23).
- (b) In the *Sūryaprajñapti* the planets are said to travel faster than the stars and the stars faster than the nakshatras. (See § 24).
- (c) According to the usual interpretation the Purāṇas tell us that the Great Bear revolves among the nakshatras, the time of a complete revolution being 2,700 years. (See § 22).

In spite of the general vagueness and certain inconsistencies there seems to be some evidence of a knowledge of precession, but this was hopelessly masked by the extremely inaccurate length of the year and the crude methods of fixing the solstices.

The subject of precession will be again referred to when dealing with the more modern texts.¹

VEDIC CHRONOLOGY.

32. This section is headed 'Vedic chronology' because it exhibits briefly a number of arguments that have been employed to fix the chronology of the earliest Hindu works. There are many dangers for those who seek to fix a chronology by means of references to astronomical phenomena—unless those references are explicit and free from all ambiguity. In most of the cases cited below, which have already been referred to under the closely connected topic of precession, there are elements of three types which may be marked A, B and C. The first of these (A) refers to, or is supposed to refer to, a definite point in the sun's path, generally either a solstice or equinox, the second (B) refers to some particular nakshatra, and the third (C) equates the nakshatra with a particular star or constellation or a particular (fixed) position of the ecliptic. In all the very early cases A is not actually given by the text in question and in none of the cases is the equation of B with C definite. To determine A it is further often assumed that the year commenced at one of the equinoxes or solstices. The present practice in India varies considerably

¹ See § 62. See also my paper, *The Nakshatras and Precession* in the *INDIAN ANTIQUARY*, 1921.

with the locality: there are many systems in vogue and the year begins at many points. Albīrūnī noticed this and mentions (ii. 8) the months Chaitral Bhādrapada, Kārttika, Mārgaśīrsha as marking the commencement of the year in different parts of India; and the practice at the present time is similar but rather more various. Again if it were recorded that a solstice or equinox (A) were marked by a certain star (B), then, owing to the precession of (A), the combination (AB) would enable us to deduce an approximate date, if both (A) and (B) were unambiguous. Suppose now another more or less independent record gave one or both of the elements (ab) and a third one ($\alpha \beta$) and so on: then it is obvious that (Ab), (A β), (aB), etc., are more or less meaningless combinations, from which no legitimate deductions may be made. These remarks apply to all of the cases cited except numbers xii and xiii which, however, also are based upon precession. The last case is of different type altogether—relating to an eclipse of the sun.

With these preliminary cautions the following arguments, that have been employed to fix the chronology of the early Indian texts, are exhibited in a condensed forms:—¹

- (i) The early lists of the nakshatras all begin with Kṛittikā and possibly this corresponded with the beginning of the year, and possibly the year began at the vernal equinox: and the vernal equinox was marked by the Pleiades about 2300 B.C.
- (ii) Jacobi holds that the 'frog hymn' (RV. vii, 103) indicates that the year began at the summer solstice, and that the sun was then in Phalgunī; and the date when the summer solstice occurred in the constellation usually identified with Phalgunī was approximately 4500 B.C.
- (iii) Another text (TS. 'vii, 4) says—'The mouth of the year is the Phalgunī full moon.' Assume that this marked the winter solstice and the date arrived at is about 4000 B.C.
- (iv) The same passage indicates that the full moon in Chitrā may mark the beginning of the year and by a similar process of reasoning the date arrived at (for the winter solstice) is about 6000 B.C.
- (v) The context of the same passage has also been interpreted to indicate a year beginning at the winter solstice with the full moon in Maghā and the date arrived at is 2350 B.C.
- (vi) The *Jyotiṣha Vedāṅga* makes what is possibly the earliest definite statement connecting the year with the nakshatras. The winter solstice is said to be marked by Śravishṭhā, and, if Śravishṭhā is to be identified with α and β Delphini, this occurred about 1400 B.C.
- (vii) The *Mahābhārata* (i. 71) appears to mark the winter solstice by Śravaṇa and if this nakshatra is to be identified with α Aquilæ the date is approximately B.C. 260.

¹ For references see the table below, pp. 31 32

- (viii) The *Paitāmaha Siddhānta* gives us the earliest definite date, namely A.D. 80, and makes the year begin with the sun in Śravishtā; and, if Śravishtā is to be identified with α and β Delphini, this would make the year begin about twenty days after the winter solstice. This is in accordance with the known practice and is an indication that earlier texts may possibly carry the same meaning.
- (ix) The *Sūryaprajñapti* makes the cycle begin with the winter solstice in Abhijit; and, if Abhijit is to be identified with α Lyrae, this occurred about A.D. 880.
- (x) Since another name for Mārgasīrsha is Āgrahāyana, which means 'belonging to the commencement of the year;' and since, according to Tilak, this is to be equated with the autumnal equinox, the date 4000 B.C. is once more achieved.
- (xi) Tilak sees in RV. i. 105 a reference to the heliacal rising of Sirius at the vernal equinox, which takes us back to about 4500 B.C.
- (xii) The nakshatra Kṛittikā is said not to 'move away from the eastern quarter, while the other asterisms do move from the eastern quarter' (ŚB. ii. i, 2²⁴). Dikshit thinks that this means that Kṛittikā was on the equator and this 'conclusively shows that the age of the Brāhmaṇas, or more properly, of that portion in which the passage occurs is about B.C. 3000.' But may it not mean that Kṛittikā (like Aries) is the first division of the ecliptic and that the first point of Kṛittikā always marks the equinox?
- (xiii) In MBU i. 4 is a supposed reference to the movement of the pole star. The Hindu name for the pole star is dhruva (fixed) and Jacobi argues that this term could only have been applied to α Draconis; and since α Draconis was approximately at the pole of the equator at about 2800 B.C. the references to Dhruva must have originated about that time.
- (xiv) Ludwig attempts to identify an eclipse referred to in the Rig Veda with one that actually took place in 1029 B.C.

These cases are shown in a somewhat different way in the following table :—

A Time of year.	B Supposed position of sun marked by	C Representative star of B.	Longitude of C at A.D. 100.	Date deduced. Circa.	References.
a. Summer solstice .	Chitrā . . .	α Virginis . . .	177° 26'	B.C. 6200 .	TS. vii, 48.
b. Vernal equinox .	Heliacal rising of Sirius.	α Canis Majoris .	78° 0'	" 4771 .	RV. i, 105 ; TILAK, Orion Ch. V.
c. Vernal equinox .	Mṛigaśīras .	λ Orionis . . .	57° 16'	" 3910 .	TILAK, Orion Ch. iv.
d. Summer solstice .	Phalgunī . .	β Leonis or	145° 22'	" 3870 .	RV vii, 103 ⁴ ; TS vii, 4 ⁶ ; JACOBI <i>Ind. Ant.</i> xxiii. 1894.
		γ Leonis . . .	134° 43'	" 3090 .	154, f.

A Time of year.	B Supposed position of sun marked by	C Representative star of B.	Longitude of C at A.D. 100.	Date deduced. Circa.	References.
e. Summer solstice	Maghā . .	α Leonis . .	123° 31'	B.C. 2300 .	TE vii. 4 ^s .
f. Vernal equinox	Kṛittikā . .	η Jauri . .	33° 34'	" 2300 .	AV. xix, 7, etc.
g. Winter solstice	Śravishtā . .	α Delphini . .	291° 0'	" 1400 .	JV 5-7.
		β " . .	290° 0'	" . .	....
h. Winter solstice	Śravaṇa . .	α Aquilae . .	275° 2'	" 260 .	MB. i, 71.
i. Summer solstice	Full moon in Abhijit.	α Lyrae . .	258° 45'	A.D. 880 .	JASB, 1880, p. 112.
j. Vernal equinox	Āsvini . .	β Arietis . .	7° 34'	B.C. 436 .	
		ζ Piscium . .	353° 24'	A.D. 601 .	
k. Twenty days after winter solstice.	Śravishtā . .	β Delphini . .	290° 0'	" 80 .	PS. xii, 2.
l. Summer solstice	Āślesha . .	η Hydrac . .	105° 56'	B.C. 1035	
		δ " . .	103° 58'	" 900 .	
m. Summer solstice	Punarvasu . .	α Geminorum . .	83° 52'	A.D. 540 .	PS. iii 21; BS. iii, 1.
		β " . .	87° 5'	" 313 .	
n. Kṛittikā does not move from east		η Tauri . .	33° 34'	B.C. 3000	ŚB. ii, 1, 2 Ind. Ant. 1895, xxiv 245.
o. The pole star is 'fixed'		α Draconis . .	130° 32'	" 2800	Ind. Ant. 1894, xxiii, 157.

This section may be appropriately closed with summaries of the views of Mr. B. G. Tilak and Mr. R. Shamasastri. "I tried to show," writes Tilak,* "that . . . the astronomical statements found in the Vedic literature supplied us with far more reliable data for correctly ascertaining the ages of the different period, of Vedic literature. These astronomical statements, it was further shown, unmistakably pointed out that the vernal equinox was in the constellation of Mṛiga or Orion (about 4500 B.C.) during the period of the Vedic hymns, and that it had receded to the constellation of the Kṛittikās, or the Pleiades (about 2500 B.C.) in the days of the Brāhmaṇas. Naturally enough these results were, at first, received by scholars in a sceptical spirit. But my position was strengthened when it was found that Dr. Jacobi, of Bonn, had independently arrived at the same conclusion, and soon after scholars like Prof. Bloomfield, M. Barth, the late Dr. Bühler and others more or less freely acknowledged the force of my arguments. Dr. Thibaut, the late Dr. Whitney and a few others were, however, of opinion that the evidence adduced by me was not conclusive. But the subsequent discovery, by my friend the late Mr. S. B. Dixit, of a passage in the Shatapatha Brāhmaṇa, plainly stating that the Kṛittikās never swerved-

* *The Arctic home in the Vedas*, p. i.

in those days, from the *due east*, i.e., the vernal equinox, has served to dispel all lingering doubts regarding the age of the Brāhmaṇas; while another Indian astronomer, Mr. V. B. Ketkar...has mathematically worked out the statement in the Taittirīya Brāhmaṇa (iii, 1, 5), that Bṛhaspati, or the planet Jupiter, was first discovered when confronting or nearly occulting the star Tishya, and shewn that the observation was possible only at about 4650 B.C. thereby remarkably confirming my estimate of the oldest period of Vedic literature. After this, the high antiquity of the oldest Vedic period may, I think, be now taken as fairly established.*"

Another speculation of a somewhat similar type is exhibited in the late Mr. R. Shamasastri's *Gavām Ayana—an Exposition of a forgotten sacrificial Calendar*. I do not follow altogether Mr. Shamasastri's argumentation and therefore give his own summary. He writes¹—"The so-called 'Gavām Ayana, or 'Cow's Walk'...is a sacrificial era of intercalary days in terms of which the Vedic poets counted their years. As Prajāpati is one of the most important names of this intercalary day, the starting point of this era in 3101 B.C. must necessarily mean the creation of Prajāpati, whom later commentators seem to have mistaken for the world's creator himself, the son of Viṣṇu. Apart from keeping an account of the days reckoned from this starting point of their era, they also counted the intercalary days by means of formulas or of sets of syllables of special Vedic hymns, which they compiled and recited on each of their recurring sacrificial days. Side by side with this sacrificial era, there existed a vulgar era, the Kali era, in which the common people counted their years *seriatim* in contrast with the priestly method in counting the years in terms of yugas or cycles of four years each....When the total number of these cycles or cyclic days amounted to 460 or 465, corresponding to 1840 or 1860 years, this era together with its cyclic sacrifices came to an end, leaving the vulgar era alone to continue."

THE PLANETS.

33. The fact that the Vedic hymns were largely inspired by celestial objects would dispose one to believe that the Vedic seers were familiar with all the more striking astronomical phenomena; but, as far as the evidence goes, we are almost compelled to believe that the planetary motions were considered unimportant: at any rate they were not recorded as phenomena of special significance.² As already pointed out (§ 16) the mention of the number five, or seven is the principal basis for the suggestion of planets.

* The reader should bear in mind that, of the authorities referred to by Mr. Tilak, Whitney and Thibaut were by far the most competent to judge; and that the subsequent 'discovery' by Dixit by no means clinches the matter. (see § 32, xii) and that the calculations of Mr. Ketkar, however accurate they may be, are of little value as evidence.

¹ page 147.

² I do not hold the opinion that the Hindus did not observe and distinguish the several larger planets in early times—it is inconceivable; but I do consider that none of the Vedic passages so far cited is proven to be a record of such observation. Certain passages in the *Jātakas*, the *Mahābhārata* and the *Rāmāyaṇa* imply a knowledge of the planets that might very well be of an early date, but mention of the planets should be scrutinised with care. An interesting example occurs in the *Bṛhadāraṇyaka Dharma Sūtra* (ii, 5, 99), where the nine planets, including Rāhu and Ketu, are mentioned. But in the same *Khaṇḍikā* two later authors are named (1) and Bühler strongly cautions us as to the genuineness of this portion of the text. (Nevertheless in the *Indian Antiquary* of 1918 (p. 112) we find this very example referred to as completely authoritative, and Bühler's warning completely ignored !

The more important Vedic passages that have been cited as records of the planets are as follows¹—

"Seven the quarters of the world with different suns, seven the ministrant priests, seven are the divine Ādityas. With these, O Soma, guard us." (RV ix, 114³)

"May the five bulls (*ukshāṇas*) who abide in the centre of the expanded heavens, having together conveyed my prayers quickly to the gods, return." (RV i, 105¹⁰).

"Seven sages with five ministering priests (*adhvaryus*) attend the station that is prepared for the rapid (Agni)." (RV iii, 7⁷).

"Bṛihaspati, when first being born from a great light or brightness in the highest heaven, seven-mouthed, of a powerful nature, seven-rayed, with a deep sound, blew away the darkness." (RV iv, 50⁶).

"The cloud-born Vena sends the water from the firmament; the back of the azure (sky) is beheld. He shone on the summit of the water in the heaven." (RV x, 123²).

The other Vedas, the Brāhmaṇas, the Upanishads, and even Manu, record nothing about the planets that can be grasped. The *Mahābhārata* mentions them by name,² and the *Rāmāyaṇa* alludes to individual planets on several occasions,³ while the Purāṇas hint at a planetary cult; but tittle, definitely astronomical, relating to the planets occurs in any of these works, except perhaps the Purāṇas. The earlier formal astronomical texts, such as the *Jyotiṣa Vedāṅga*, make no reference to the planets; but, of course, this purely negative evidence does not exclude the possibility of some knowledge and investigation of them from the astronomical point of view. In the *Yājñavalkya-smṛiti* (? 5th century A.D.) certain ritualistic details relating to the worship of the planets are given, and about the same period the motions of the planets began to be studied scientifically.

The order in which the planets are placed in the later Hindu works is a matter of some interest. There may be said to be two types of sequence (a) the natural order or order of their distance from the earth, (b) astrological orders. Of the former there are two examples—the slightly incorrect order of the earlier Greeks (Plato, Aristotle, Eratosthenes, etc.), who placed Venus nearer to the earth than Mercury; and the correct order which came into use about the time of Hipparchus. Of the astrological orders there are several. Of these the week-day order is the best known; and there is the domiciliary order, and the several orders of 'terms' or 'limits.' In the great majority

¹ Hillebrandt thinks the five *adhvaryus* are the five planets. Oldenberg suggests that the Ādityas correspond to the seven planets. See appendix i; also H. OLDENBERG *Die Religion des Veda*, 185 f.; O. SCHRADER in *EFE* ix, 568.

Tilak equates Vena with Venus (*Orion* p. 162 f.) but this is not generally accepted.

Thibaut thought that the planet Jupiter was referred to under the name Bṛihaspati in the early texts, and this notion has recently been revived by Fleet but controverted by A. B. Keith. See *JRAS* 1911 pp. 514 f. 794 f. and 1119 f. Fleet quotes the following in support of his views: "Bṛihaspati, when first being born, came into existence over against the nakṣatra Tishya." (TB iii, 1¹).

² MB ii, 11³⁷.

³ R ii, 4; ii, 25; ii, 26; ii, 100; iii, 46; iii, 49; vi, 4; vi, 54; vi, 103; etc. See appendix ii.

of cases the Hindus, although they were aware of the correct order, place the planets in the week-day order. Albīrūnī says (i. 125): "It is the custom of the Hindus to enumerate the planets in the order of the week-days. They will persist in using it in their astronomical hand books, as well as in other books, and they decline to use any other order, though it be much more correct." They also enumerate them in the domiciliary order and the order of the limits or terms with reference to Pisces and Aries.

These orders are exhibited in the following table:—

Classical Greek.	Later Greek (the correct order).	Week-day order.	Domiciliary order.	Order of terms or limits for Aries.	Order of terms or limits for Pisces.
Moon . . .	Moon . . .	Sun . . .	Saturn . . .	Jupiter . . .	Venus.
Sun . . .	Mercury . . .	Moon . . .	Jupiter . . .	Venus . . .	Jupiter.
Venus . . .	Venus . . .	Mars . . .	Mars . . .	Mercury . . .	Mercury.
Mercury . . .	Sun . . .	Mercury . . .	Venus . . .	Mars . . .	Mars.
Mars . . .	Mars . . .	Jupiter . . .	Mercury . . .	Saturn . . .	Saturn.
Jupiter . . .	Jupiter . . .	Venus . . .	Moon-Sun . . .	..	..
Saturn . . .	Saturn . . .	Saturn . . .	..	..	..
Aryabhaṭa . . .	The later texts give this order at least once each.	All the later texts on most occasions.	The Vishṇu Purāṇa. ii. 7 inverts this order.	Mahābhārata iii. 3.	Mahābhārata ii. 11.

Fleet points out that the later Hindu works almost invariably begin the week-day order with Sunday, not Saturday, and thinks that this is due to the influence of the Jewish-Christian week.

34: RĀHU AND KETU.—The term Rāhu appears at a comparatively late date in connexion with Hindu astronomy. It occurs in the Atharva Veda (xix. 9¹⁰), but with no certain astronomical meaning. In the Mahābhārata both Rāhu and Ketu are mentioned (ii. 11³⁷; vi. 3¹) amongst the planets while in the Rāmāyaṇa Ketu does not appear.¹ In the *Pañchasiddhāntikā* we get definite references to the head of Rāhu and also to the tail of Rāhu (e.g. ix. 6, etc.) with the astronomical meanings of the ascending and descending nodes of the moon's orbit; and in the *Bṛihat Samhitā* there is a chapter (v) on 'Rāhu's course,' which begins: "Some say that Rāhu is, forsooth, a demon's head, which, albeit severed from the trunk, yet, by virtue of having tasted nectar, has continued alive and become a Graha (i.e., 'seizer,' or 'planet'). others declare Rāhu to have a body, consisting only of head and tail, the figure of a snake. Others again tell us that the so-called son

¹ See WEBER (*Ind. Lit.* p. 250) who states that Rāhu first occurs in the Chāndogyaopaniṣad, though hardly in the sense of 'planet.' Ketu, he says, is first mentioned by Yājñavalkya.

of *Sinhikā* is incorporeal and opacous." Rāhu therefore became known as the demon of eclipses and his head was identified with the ascending node and his tail with the descending node. The knowledge implied of the inclination of the moon's orbit to the ecliptic is not exhibited in Hindu works before the introduction of western astronomy. The term *Graha*, which means 'seizer,' was applied to the planets as powers which lay hold of the fates of men, and quite naturally embraced the demon of eclipses.⁽¹⁾ The term *Ketu* is, as *Albīrūnī* pointed out (ii. 234) seldom used by the Hindus to denote the descending node, and it is sometimes employed to denote comets. The *Nava-graha* or nine planets (Sun, Moon, the five planets, Rāhu and Ketu) later on developed into minor deities.²

35. WEEK DAYS.—The Hindus at a comparatively late period employed the planetary names of the days of the week as follows:—

	Hindu names.	Corresponding planets.
Sunday	Rāvi-vāra	Sun.
Monday	Soma-vāra	Moon.
Tuesday	Maṅgala-vāra or Bhauma-vāra	Mars.
Wednesday	Budha-vāra	Mercury.
Thursday	Bṛihaspati-vāra or Guru-vāra.	Jupiter.
Friday	Śukra-vāra	Venus.
Saturday	Śani-vāra	Saturn.

The Hindu names are exact equivalents of the Roman names, which came into use in the west about the beginning of the Christian era. Now the week-day order of the planets is an artificial one based upon the natural order—Saturn, Jupiter, Mars, the Sun, Venus, Mercury, the Moon, and was developed thus: Saturn is the lord of the first hour of the day, Jupiter the lord of the second hour and so on; consequently the lord of the 25th hour, or first hour of the second day, is the Sun; the lord of the 49th hour or first hour of the third day is the Moon; and so on. The 24 hour day is therefore essential to the scheme, and the division of the day into 24 hours nowhere appears in India—so we must conclude that the week-day order of the planets is of non-Indian origin. Again the week-day order properly begins with Saturn (Saturday) whereas the Hindu week begins with Sunday—and this is probably due to the same influence as with us (the Jewish-Christian week).³

¹ The Gnostics placed the head of the dragon at the ascending node and its tail at the descending node. In the west *Caput Draconis* and *Cauda Draconis* were, in connexion with genethliacal notions, assimilated with the planets at a fairly early date. Tertullian (A.D. 160—230) refers to this and so does Proclus (A.D. 412—485). See FOUCHÉ LECLERCQ, *L'Astrologie grecque*, p. 122, etc.

² See appendix i.

³ *Ādi-vāra*, 'the beginning day' sometimes used instead of *Ravi-Vāra*. Brahmagupta states that the process of creation began on a Sunday.

The earliest known use in Indian inscriptions of a planetary day dates from A.D. 484, and down to A.D. 800 there are a few authentic instances. After A.D. 900 the planetary days became a common item of the Hindu calendar.¹

36. HELIACAL SETTINGS AND RISINGS.—Notwithstanding Tilak's ingenious attempt to discover a reference to the heliacal rising of Sirius in RV. i, 105¹¹ the topic is not really referred to in any Hindu work before the Greek period, the earliest references being in the *Āryabhaṭīya*, the *Pañchasiddhāntikā* and the *Bṛihat Saṃhitā* of Varāha Mihira. The phenomenon was introduced as an astrological one and its astrological significance has completely prevailed, no astronomical meaning whatever being attached to it in early Indian texts.

The distances in degrees from the sun at which the stars and planets become visible are stated in the texts to be as follows:—

Stars.	C. ²	Planets.	A.	B.	C. ²
Agastya (Canopus)	13°	Moon	12°	12°	...
		Mars	17°	19°	17°
Mṛigavyādhā (Sirius).	13°	Mercury	13°	17°	12—14°
Brahmahridaya (Capella)		Jupiter	11°	13°	11°
Svātī, Chitrā, Jyeshthā		Venus	9°	11°	8—10°
Punarvasu, Abhijit		Saturn	11°	15°	15°
Hastā, Śravana, Phalgunī	14°				
Śravishtā, Rohiṇī, Maghā					
Viśākhā, Aśvinī	15°				
Kṛittikā, Anurādhā, Mūl.					
Aśleshā, Ārdrā, Ashā hās	21°				
Bharanī, Pushyā, Mṛigaśiras					
Remainder	17°				

37. THE JUPITER CYCLE.—The earliest reference to the cycle of Jupiter is in the *Bṛihat Saṃhitā*.³ In comparatively modern times the Jupiter cycle is employed in dating inscriptions, etc., but there is no evidence that indicates its employment or a knowledge of it in India earlier than the fifth or sixth century of our era.

¹ Fleet JRAS, 1912, p. 1039 f.

² The values under A are from Āryabhaṭa, under B from the *Pañchasiddhāntikā* and those under C from the *Sūrya Siddhānta*.

³ Ch. viii. See also the *Sūrya Siddhānta*, i, 55 and xiv, 17; also Albrūn's *India*, ii, 123 f.

While the Jupiter cycle is not a marked feature of the Greek astronomical teaching the twelve and sixty year periods were well known to them.¹ The sixty year cycle with the Chinese is a double cycle of 12×5 years with which is connected another double cycle 10×6 years; and the Chinese seem to begin their cyclic reckoning with the year 2637 B.C. The Annamese, Cambodians, and Siamese also use the sixty year cycle. In the early cases, at least, the Hindu cycle is a compound one of 5×12 years.² See also paragraph 61(f).

38. MOUNT MERU.—Brahmagupta says—"Manifold are the opinions of the people relating to the description of the earth and to Mount Meru, particularly among those who study the Purāṇas and the religious literature. Some describe this mountain as rising above the surface of the earth to an excessive height. It is situated under the pole, and the stars revolve round its foot, so that rising and setting depends upon Meru....The day of the angels who inhabit Meru lasts six months, and their night also six months."

Āryabhaṭa, who taught that the earth was a rotating sphere, argued that Meru had no absolute height. The Purāṇas, however, make it 80,000 or 86,000 yojanas high, etc. For information about the various views regarding Mount Meru consult Albīrūnī (Ch. xxiii), the several Purāṇas, Patañjali (iii. 26) and comment thereon, etc.; but very little of astronomical interest will be found beyond that given by Brahmagupta and Āryabhaṭa. The notion of Mount Meru is a late introduction and is possibly of foreign origin.³ Albīrūnī pointed out (i. 249) that the Hindu conception of Meru was similar to that of the Zoroastrians, who place at the centre of the world the mountain Gīrnagar.⁴ The name variants Neru, Sineru and Sumeru also seem to indicate a foreign origin⁵ and the geographical scheme generally accompanying the descriptions of Meru may be connected with the Avestan scheme of seven districts; and Mount Meru as the abode of the gods recalls to us the Olympus of the Greeks.

¹ FRAZER writes:—"With the thirty years' cycle of the Druids we may compare the sixty years' cycle of the Boeotian festival of the great Dædala." (*Balder the Beautiful*, ii, 77 n.). Again he writes, on what authority is not known: "It seems further, that in India a much older cycle of sixty years was recognised." *ib.* ii, 77 n.

² Sewell and Dikshit, following J. Burgess, state that the years of the Jupiter cycle were probably introduced into India about A.D. 350 and were certainly in use in A.D. 530. *Indian Calendar*, p. 36.

³ Ed. J. H. Woods, p. 254 f.

⁴ The Tera of the Avesta. See also foot-note 4, p. 19.

⁵ JRAS, 1917, p. 365.

CHAPTER VI.

The introduction of Greek astronomy.

39. That the Hindu astronomical teaching from about A.D. 400 onwards is dominated by what is known as the Greek system of astronomy is now generally accepted. To those who are well acquainted with the Greek teaching and with the Hindu works of the period this is obvious. A fair amount of the evidence can be put in a summary form, but it must, however, be borne in mind that the most appropriate demonstration for such a connexion generally consists of cumulative evidence, on which the judgment of the expert is of particular value. Most scholars, Indian¹ and European, accept the judgment of the expert in this matter and allow that the introduction of western astronomical knowledge took place about A.D. 400.

Of particular evidence that can be conveniently marshalled we have explicit statements of early Hindu writers, the employment of Greek technical terms in Hindu works of the critical period, and the introduction of ideas entirely new to India but which had been for some time taught by the Greek astronomers.

40. Varāha Mihira, Brahmagupta and others refer to Greek astronomers. In the *Bṛihat Samhitā* (ii, 7) we read—"Even the Mlechchhas and the Yavanas who have studied the science are respected as Ṛishis. Such being the case, if the Jyotishika is a Brahman, who will deny him respect?" Albīrūnī(i, 23) also quotes this and emphasises the indebtedness of the Hindus to the Greeks. Brahmagupta refers to the Yavana siddhāntas; and there is a significant passage in the *Sūrya Siddhānta*² that points to a western source of information. That the Pauliśa and Romaka Siddhāntas are of western origin there can be little doubt. The former is possibly connected with the work of Paulus Alexandrinus (circa A.D. 378); and Romaka is stated by Varāha Mihira to be situated 90 degrees west of Laṅkā.

These references to Greek teachers and works may seem rather meagre to the western reader, but the custom among Hindu writers was ever to avoid reference to any foreign author or work in their own productions, which, they were constrained to assume, were either traditional or inspired. The references to the Yavanas mentioned above are therefore somewhat extraordinary and may be accepted as adequate.

41. Many Greek technical terms were introduced at the period, particularly in the astrological works, but also in those devoted to astronomy. The following are some of the many terms employed by Varāha Mihira and others:—

Greek terms.	Hindu terms.	Greek terms.	Hindu terms.
κέντρον . . .	kendra.	λεπτόν . . .	liptā.
γωνία . . .	kona.	φάσος . . .	vedī.
τρίγωνον . . .	trikoṇa.	δρεκάνος . . .	dreshkana.
ἡμερίδιον . . .	harija.	παναφάρος . . .	panaphara.
ῥάση . . .	horā.		

and many other astrological terms.³

¹ There are, however, many Indians, who, influenced by sentiment, feel unable to accept this view.

² See appendix ii, p. 108.

³ See appendix i.

The signs of the zodiac were not employed by the Hindus at all in the early period. Their names appear in two forms in the later works, either as translations or transliteration of the western terms.

Hindu names for the signs of the zodiac.		Greek names.
(1)	(2)	
Mesha (a ram), Aja (he-goat)	Kriya	Κριός
Vṛisha (a bull)	Taururi	Τάυρος
Mithuna (a couple)	Tilūma	Δίδυμος
Karkata (a crab)	Karka	Καρκόνος
Simha (a lion)	Leya	Λέων
Kanyā (a girl)	Pāthēna	Παρθένος
Tulā (a balance)	Juka	Ζυγός
Vṛīschika (a scorpion), Ali (a bee)	Kaurpya	Σκορπιος
Dhanus (a bow)	Taukshika	Τοξότης
Makara (a marine monster), Mṛiga (antelope)	Ālokera	Ἀιγοκέρας
Kumbha (a pot)	Hṛidoga	Ὑδροχόος
Mīna (a fish)	Ithusi	Ἰχθύς

The Greek names for the planets were used also, but only occasionally. The common Hindu names are indigenous. (See page 101).

42. If we examine the topics dealt with in Hindu works prior to A.D. 400 and those dealt with in later works and differentiate, we get a number of new topics, most of which are common to the Greek system; and the same applies to the methods employed. The details are exhibited in other parts of this book, and we present here only some examples of the changes effected.

- The nakshatra divisions of the ecliptic were almost altogether superseded by the signs of the zodiac.
- The motions of the planets, which in the early period had not been dealt with at all, were examined in detail and explained by the method of epicycles, after the Greek fashion.
- The notion of parallax and methods of calculating it were introduced.
- Methods of calculating eclipses, entirely new to Indian works, were introduced.
- The notion of heliacal settings and risings of heavenly bodies was introduced, chiefly with astrological applications.

- (f) Correct rules for calculating the length of the day and night and oblique ascensions, etc., were introduced.
- (g) The length of the year was revised.
- (h) The planetary week-day names were introduced.

There is a great deal of other evidence besides, some of which can only be appreciated by a detailed study of the Greek and Indian rules, and some suggests rather than proves a connexion. There is also the indirect evidence of the earlier Hindū astronomers whose methods and rules were wholly discarded by the later astronomers, and lastly there is evidence that is not astronomical at all.¹

¹ See my paper *Influence grecque dans le développement des mathématiques hindoues* SCIENTIA, 1919. Vol. xxv, pp. 1—14.

CHAPTER VII.

The astronomers of the second period.

43. With the introduction of Greek methods this account of the development of astronomy in India might, with some propriety, cease; since the subsequent modifications of the system expounded have very little real historical significance. But, as already explained, the Hindu-Greek astronomy has by some what artificial means indeed, attained sufficient importance to warrant some special treatment, and a section will therefore be devoted to it. It is unfortunate that the early European investigators into the history of Hindu astronomy attached far too much importance to the more modern texts and almost completely ignored the early ones. This was remedied to some extent by the publication of the *Pañchasiddhāntikā* in 1889 but this work is not generally available and its form of presentation makes it almost a sealed book to the ordinary reader. Other Hindu works of the period and of later times differ from the teaching of the *Pañchasiddhāntikā* principally in matters of detail; the later ones introduce greater cycles, and attempt to exhibit a greater accuracy but with no very great success; they are more elaborate in detail but hardly more efficient. In the following section an attempt will be made to exhibit the Hindu methods as represented in the earlier of these works. The more important emendations and additions of the later writers will be noticed also; so that the section will give a fairly complete survey of the Hindu astronomical teaching that has obtained during the last sixteen hundred years.

Our principal sources of information for this period are the *Āryabhatīya* of Āryabhata (circa A.D. 628), Varāha Mihira's *Pañchasiddhāntikā* written about A.D. 550, the *Brāhmasphuṭasiddhānta* of Brahmagupta (A.D. 628), and the later *Sūrya Siddhānta* of about A.D. 1000; and very considerable use has been made of Albīrūnī's *India* (A.D. 1031).

THE ASTRONOMERS.

44. Before exhibiting the astronomical methods of this period we may refer to those astronomers whose names have been handed down to us. The most renowned of these are Puliśa, Āryabhaṭa, Varāha Mihira and Brahmagupta. There are also works of importance whose authors are unknown and there are certain teachers mentioned who are now no more than mere names.

Varāha Mihira says: "There are the five following siddhāntas—the Paulīśa, the Romaka, the Vāsishṭha, the Saura and the Paitāmaha. Out of these five the first two have been explained by Lāṭadeva. The siddhānta made by Paulīśa is accurate, near to it stands the siddhānta proclaimed by Romaka, more accurate is the Sāvitra (Saurā), the two remaining being far from the truth." He also refers to Simhāchārya, Āryabhaṭa and the Yavanas as teachers. Lāṭāchārya he tells us (PS. xv. 18) reckoned time from sunset at Yavanapura, while Simhāchārya reckoned from sun rise at Laṅkā.

Brahmagupta says: "One of the siddhāntas is the *Sūrya*, others are *Indu*, *Puliśa*, *Romaka*, *Vāsishṭha* and *Yavana*; and, though the siddhāntas are many, they differ only in words, not in the subject matter. He who studies them properly will find that they agree with each other." He refers to *Āryabhaṭa* on many occasions, and also to *Garga*, *Puliśa*, *Śrīsheṇa*, *Vishṇu-chandra*, *Pradyumna*, *Lāṭa* and *Siṃha*.

Albīrūnī mentions the same five siddhāntas as *Varāha Mihira*, as well as that author's *Pañchasiddhāntikā*. He makes *Lāṭa* the author of the *Sūrya Siddhānta*, states that the *Romaka* is so called after the city of *Rūm*, and that it was composed by *Śrīsheṇa* and that the *Pauliśa Siddhānta* was so called after *Pauliśa* the Greek. Of *Āryabhaṭa*'s and *Brahmagupta*'s works he gives some accounts and many quotations therefrom. He mentions also as astronomers the following—*Balabhadra*, *Bhānuyaśas* *Surgriva*, *Vijayanandin*, *Vitteśvara*, *Utpala*, and *Āryabhaṭa* the younger of *Kusumapura*.

Of *Lāṭa*¹ and *Śrīsheṇa* we know practically nothing, but *Brahmagupta* tells us that *Śrīsheṇa* took from *Lāṭa* the rules concerning the mean motions of the planets and from *Āryabhaṭa* those concerning the true motions of the planets. According to *Thibaut* it is possible that *Śrīsheṇa* recast the *Romaka Siddhānta* and this is more or less indicated by *Albīrūnī*. Of *Lāṭa*'s connexion with the *Sūrya Siddhānta* we have no further information than *Albīrūnī*'s bare statement.

GARGA.—In the *Mahābhārata* we are told that "Garga, the great Rishi" became astrologer to *Prithu*. *Kālaṇṇāna* or 'knowledge of time' is especially attributed to him and he is also associated with *Kālayavana*: 'Kālayavana who is endued with Garga's power' (xii, 340, 95); and he is credited with a 'thorough knowledge of times and mastery of the science of stars.' (ix, 37, 14).² According to the *Vishṇu Purāṇa* (ii, 5); "The ancient sage Garga, having propitiated *Śeṣha*, acquired from him a knowledge of the principles of astronomical science, of the planets, and of the good and evil denoted by the aspect of the heavens."

We have not any of this somewhat mythical Garga's original work; but the *Gārgī Samhitā* was possibly composed about the beginning of the Christian era³ and was an astrological treatise. It appears to have contained a chapter in the style of a *Purāṇa*, in which were given references to the invasion of the Greeks, to their conquest by a *Śaka* king, and to the overthrow of the *Śakas* by another power.⁴ *Varāha Mihira*'s *Bṛihat Samhitā* appears to be largely based upon the work of Garga: the following are some of *Varāha Mihira*'s quotations:—

"Bhagavan Garga says—'That prince meets with ruin who does not support a *Jyotiṣhika*, etc.'"⁵

¹ The *Jyotiṣha Vedāṅga* has been attributed to an unknown *Lagadha* or *Lagata*, who, *Weber* suggests, might be the same as *Lāṭa* (*Ind. Lit.*, p. 61).

² W. HOPKINS, *The Great Epic of India*, p. 15.

³ See J. BENTLEY, *Historical Review of Indian Astronomy*, p. 66; See W. JONES' *Works* IV: 64.

⁴ E. J. RAPSON, *Ancient India*, p. 131.

⁵ BS. ii. 7.

"And I say, on the authority of Garga, the ancient, that the seven Rishis stood in Maghā, etc." ¹

"It was in such a grove of Mount Meru, the abode of the Devas, that Nārada communicated to Bṛhaspati the laws of the Rohiṇī yoga. The same laws have since been taught by Garga, Parāśara, Kaśyapa and Maya to numbers of their disciples. Having examined these truths, I propose to write a brief treatise, etc." ²

"I have spoken of the comets, but not before having examined what is in the books of Garga, Parāśara, and Asita Devala, and in other books, however numerous they be." ³

45. PULIŚA.—Albīrūnī couples the names of Puliśa and Āryabhaṭa together on many occasions; so often, indeed, that had we only Albīrūnī to rely upon we should hardly be able to distinguish between the two with regard to their work and teaching. They always appear to be in agreement, and are both abused by Brahmagupta. "Āryabhaṭa, Puliśa, Vāsishṭha, and Lāṭa agree in this, that when it is noon in Yamakoṭi, it is midnight in Rūm, beginning of the day in Laṅkā, and the beginning of the night in Siddhapura, which is not possible, if the world is not round." "Āryabhaṭa, the elder, and Puliśa compose the manvantara from 72 chaturyugas, etc." and, "according to Āryabhaṭa and Puliśa, the kalpa and chaturyugas begin with midnight, etc." Regarding Brahmagupta's hatred—"In this respect Āryabhaṭa and Puliśa are the same to him," writes Albīrūnī.

Āryabhaṭa, the younger, speaks highly of the intelligence of Puliśa, and Albīrūnī was engaged in translating his works. Unfortunately this translation is not available, but, in the *India*, Albīrūnī gives several direct quotations from the *Puliśa-Siddhānta*. For example:—"Puliśa says in his *Siddhānta*: 'Puliśa, the Greek, says somewhere that the earth has a globular shape. Besides, all scholars agree on this head as Varāhamihira, Āryabhaṭa, etc.'"

In his list of Hindu works on astronomy, Albīrūnī states that the *Puliśa-Siddhānta*, composed by Puliśa, was so called from Pauliśa, the Greek, from the city of Saintra, which he supposes to be Alexandria. It has been suggested that this Pauliśa is the Paulus of Alexandria, who in A.D. 378 wrote an introduction to astrology which has come down to us.

According to Weber, Puliśa was a contemporary of Āryabhaṭa and the two were rivals, while Kern places Puliśa a century before Āryabhaṭa.

For Puliśa's astronomical views we have a brief summary in the *Pañchā-siddhāntikā* and Albīrūnī's quotations and references, which, we may assume with some warrant, accurately represent the views of Puliśa. According to Puliśa the universe consists of earth, water, fire, air and ether. He refers to the hypothesis of Pauliśa the Greek that the earth is a globe, otherwise, he points out, day and night would not be different in winter and summer.

¹ BS. XIII, 2-3.

² BS. XXIV, 2. Of Parāśara and Kaśyapa as actual astronomers or astrologers we have no information. To Maya is attributed the authorship of the *Surya Siddhānta*. See appendix II, p. 108.

³ BS. XI, 1. Asita Devala is now a mere name to us.

Mount Meru is above the pole, and the earth is fastened to the two poles and held by the axis, and the wind makes the sphere of the stars to revolve. When the sun rises over the line which passes both through Meru and Laṅkā that moment is noon at Yamakoṭi, midnight to the Greeks and evening at Siddhapura.

Such notions are indeed common to all the works of the period but in addition Puliṣa seems to have been an authority as a calculator. His values of π (particularly $3\frac{177}{128}$) are often quoted and the table of sines appears to be attributed to him.¹ He appears to have introduced new methods of calculating the *ahargaṇa* (see § 61). The numerical elements of his astronomical scheme are given in appendix iii.

46. ĀRYABHAṬA.—In works on Indian astronomy references to the famous Āryabhaṭa abound, and, from the time of Varāha Mihira to the present day we find numerous quotations from him. Unfortunately, a great many of these quotations are second hand; for it appears that the original works were practically lost for centuries. At the beginning of the eleventh century Albīrūnī wrote:² "I have not been able to find anything of the books of Āryabhaṭa. All I know of him I know through the quotations from him given by Brahmagupta"; and, at the beginning of the nineteenth century, we are told by Colebrooke³ that "a long and diligent research in various parts of India failed of recovering the Algebraic and other works of Āryabhaṭa." Also that the original works of Āryabhaṭa were either not available, or existed only in a much mutilated condition in the fourteenth century, is indicated in the following passage from the *Mahā Āryasiddhānta*: "That (knowledge) from the Siddhānta, propounded by Āryabhaṭa, which was destroyed, in recensions, by long time, I have in my own language thus specified."⁴

Āryabhaṭa's work consists of four parts: (i) The *Gīṭikā*, which consists of ten couplets and contains astronomical tables; (ii) the *Gaṇita* consisting of 33 couplets; (iii) the *Kālakriyā*, which deals with the measure of time; and (iv) the *Gola*, or 'Sphere.' The last three sections make up the *Āryaśāṣaṭa* or work of 108 couplets, while the first part is known as the *Daśagīṭikā*. Other works have been attributed to Āryabhaṭa, but the above mentioned are probably all now known that can be justly called his. From Albīrūnī⁵ we learn that the contents of the book *Karaṇa-khaṇḍa-khādyaka* represent the doctrines of Āryabhaṭa, and that Brahmagupta wrote a commentary thereon.⁶

Āryabhaṭa tells us that 3,600 years from the commencement of the Kali-yuga 23 years of his life had passed, and possibly this (=A.D. 498) is the date of his work, or the epoch from which he reckoned;⁷ and it is this

¹ ALBIRŪNĪ *India*, i, 275, etc.

² *India*, i, 370.

³ JRAS, 1864, p. 392.

⁴ *Essays*, ii, 422.

⁵ *India*, i, 56.

⁶ In 1874 Kern published the *Āryabhaṭīya*. In 1879 Rodet gave the text and a translation of the *Gaṇita* in the *Journal asiatique*; and in 1908 the present writer contributed a paper on the *Gaṇita* to the *Journal of the Asiatic Society of Bengal* (1908, pp. 111—141). Mr. Udaya Narain Singh of Mazaffarpur has reprinted Kern's text.

⁷ *Kālikriyā*, 10.

Āryabhaṭa, who was born in A.D. 476, to whom we refer. But there was another Āryabhaṭa of some note known to Albīrūnī, who carefully distinguishes the one from the other. The more modern Āryabhaṭa he always designates as Āryabhaṭa of Kusumapura:¹ "This author," he says, "is not identical with the elder Āryabhaṭa, but he belongs to his followers, for he quotes him and follows his example." We infer from Albīrūnī's remarks that the elder Āryabhaṭa was not of Kusumapura; but Weber, Kern and Bhau Daji say distinctly that he was and the opening verse of the *Gaṇita* indicates its author as belonging to Kusumapura.²

Āryabhaṭa was an innovator. He attempted to free at least one department of knowledge from corrupt belief, and, as an almost natural consequence, the orthodox Hindu teachers opposed him. We read that Brahmagupta was so intolerant that he was blind to the truth "from sheer hatred of Āryabhaṭa, whom he abuses excessively....He is rude enough to compare Āryabhaṭa to a worm, which, eating the wood, by chance describes certain characters in it, without understanding them and without intending to draw them. 'He, however, who knows these things thoroughly stands opposed to Āryabhaṭa like the lion against gazelles. They are not capable of letting him see their faces.' In such offensive terms he attacks Āryabhaṭa and abuses him."

The cause of this vilification is Āryabhaṭa's unorthodoxy, as is indicated in other passages. For example, Brahmagupta states that Āryabhaṭa's teaching regarding eclipses was not in accordance with the Veda and "the book *Smṛiti* composed by Manu and the *Samhitā* composed by Garga, the son of Brahma," and that Āryabhaṭa "stands outside of the generally acknowledged dogma and that is not allowed." "Further," Albīrūnī writes, "Brahmagupta says that Āryabhaṭa considers the four yugas as the four equal parts of a chaturyuga. Thus he differs from the doctrine of the book *Smṛiti*....and he who differs from us is an opponent."

Later Hindu opinion was more favourable, at least in intention. In the sixteenth century Sūryadeva ascribed the acquirement of the elements of astronomy by Āryabhaṭa to supernatural agencies. A twentieth century author³ also suggests divine inspiration: "Divine favour dawned upon him; he was inspired: he gave utterance to a spontaneous outburst of astronomical knowledge, clothed in poetical language....These facts lead the learned to believe that the ten verses were inspired and could not be attributed to human authorship."

Āryabhaṭa is chiefly notable as an opposer of certain aspects of the orthodox Hindu teaching of his time. He demonstrates that Mount Meru is not really high. He teaches that the earth is a sphere and that it rotates on its axis. This revival of a Greek hypothesis, however, did not flourish in India any more than in the west. If the earth rotated "falcons, etc., could not return from the sky to their nests....and flags and similar things would, owing to the quickness of the revolution, stream constantly to the

¹ *India*, i, 176, 246, 316, 330, 335, 370.

² See my paper on *The two Āryabhaṭas* BIBLIOTHECA MATHEMATICA, 1910, pp. 289—292.

³ T. R. PILLAI *Āryabhaṭa or the Newton of Indian Astronomy*, p. 7.

west" (PS. xiii, 6-7). Āryabhaṭa maintains that eclipses are not caused by Rāhu but by the moon and the shadow of the earth "in direct opposition to all and from pure enmity," according to Brahmagupta.

The elements of his astronomy are given in appendix iii. His scheme was more or less the usual one of the time but perhaps more emphatically Greek. He states that it is founded on the *Brahma Siddhānta* and that it differs from the other siddhāntas really very little. He gives no list of the nakshatras, but speaks of them as beginning with Aśvinī¹.

47. VARĀHA MIHIRA² lived at Ujjain in the sixth century. In his astronomical calculations he employed the epoch 427 śaka (A.D. 505) and, it is believed, he died in A. D. 587.

Varāha Mihira was rather an astrologer than an astronomer, his great work being the *Bṛihat Saṃhitā*, an astrological treatise of considerable length. He also wrote other astrological works, namely the *Bṛihaj Jātaka*, *Yoga Yātrā*, etc. Fortunately for the historian of astronomy he also wrote a sort of compendium of the different systems of astronomical teaching in vogue in his time. This work was practically ignored by later Hindu writers and Albīrūnī evidently thought it of little importance. "Varāha Mihira," he tells us, "has composed an astronomical book of small compass called *Pañchasiddhāntikā*, which ought to mean that it contains the pith and marrow of the preceding five siddhāntas. But this is not the case, nor is it so much better than they as to be called the most correct one of the five."³

Albīrūnī had a very high opinion of Varāha Mihira generally, but still he is not always flattering. "He (Varāha Mihira) seems sometimes to side with the Brahmans, to whom he belonged, and from whom he could not separate himself. Still he does not deserve to be blamed, as, on the whole his foot stands firmly on the basis of truth and he clearly speaks out the truth.... Would to God that all distinguished men followed his example." But on another occasion Albīrūnī says:⁵ "You see what a self-lauding man he is, whilst he gives himself airs as doing justice to others." This remark is called forth by the notable passage in the *Bṛihat Saṃhitā* which refers to the Greeks. Again:—"What Varāha Mihira says of the astrological portents of the parvans," remarks Albīrūnī,⁶ "does not well suit his deep learning."

¹ It is related that Āryabhaṭa was known to the Arabs under the name Arjabahr and that about the ninth century they, the Arabs, learnt astronomy from the Hindus and that the word *Sindhind* was their equivalent of siddhānta. Albīrūnī definitely states that the early Muslim astronomers referred to the works of Āryabhaṭa and to other siddhāntas: For example he says that they imagined that Āryabhaṭa (*Arab 'azjabhar'*) meant a thousandth part and that afterwards they mutilated the word further and wrote *azjabhar*. Further Albīrūnī writes "The book *Sindhind* is called by them (the Hindus) siddhānta; and again "A kalpa is that space of time which Muslim authors call the year of *sindhind*; and again he says "Muslims know of the methods of the Hindus only those which are found in the *Sindhind*." (*India*, i, 153; i, 332; i, 368; ii, 19.) See also note page 49.

² See H. KERN *The Bṛihat Saṃhitā... of Varāha Mihira* (JRAS, 1870-75 and *Verspeide Geschriften*, 1913); G. THIBAUT and S. DUVÉDE *The Pañchasiddhāntikā... of Varāha Mihira*, 1899; H. P. CHATTERJEE, *The Bṛihajjātakam of Varāha Mihira*, 1912, etc.

³ *India*, i, 153.

⁴ *Id.*, ii, 110.

⁵ *Id.*, i, 23.

⁶ *Id.*, ii, 113.

Of course Varāha Mihira was not free from certain of the absurd notions peculiar to astrologers and to his time but he often displayed sound common sense. Animadverting on certain views as to the conjunctions of planets as the cause of eclipses he says: "The nature of an unlucky event is the only thing which these occurrences have in common with an eclipse. A reasonable explanation is totally different from such absurdities." He discards the notion that eclipses can be foretold by observing a mixture of oil and water,¹ but he thinks comets are beings who, having been raised to heaven on account of their merit, are now redescending, etc."

Varāha Mihira is quoted largely by Albīrūnī, principally from the *Bṛihat Samhitā* on astrological matters. His astronomical views and the contents of the *Pañchasiddhāntikā* will be dealt with below.

48. BRAHMA GUPTA ² was born in A.D. 598. His principal work was written at the age of thirty and he appears to have written another work at least as late as A.D. 665. He was the son of Jishnu of the town of Bhīllamala near Multān in the Punjab. Albīrūnī, who was engaged in translating the works of Brahmagupta, names the following:—the *Brahma Siddhānta*, the *Karaṇa-Khaṇḍa-Khādyaka* (exhibiting the doctrines of Āryabhaṭa) and the *Uttara-Khaṇḍa-Khādyaka*.³ In 1817 a translation of the mathematical portions of the *Brāhmasphuṭasiddhānta* was published by Colebrooke, and in 1902 the text of the *Brāhmasphuṭasiddhānta* was published by Pandit Sudhākara Dvivedi.

Albīrūnī, after praising Varāha Mihira, continues: ⁴ "But look for instance at Brahmagupta, who is certainly the most distinguished of their astronomers....he shirks the truth and lends his support to imposture....under the compulsion of some mental derangement, like a man whom death is about to rob of his consciousness....If Brahmagupta is one of those of whom God says, 'they have denied our signs, although their hearts knew them clearly, from wickedness and haughtiness,' we shall not argue with him, but only whisper into his ear— 'If people must under circumstances give up opposing the religious codes (as seems to be your case), why then do you order people to be pious if you forget to be so yourself'....I, for my part, am inclined to the belief that that which made Brahmagupta speak the above mentioned words ⁵ (which involve a sin against conscience) was something of a calamitous fate, like that of Socrates, which had befallen him, notwithstanding the abundance of his knowledge and the sharpness of his intellect, and notwithstanding his extreme youth at the time, for he wrote the *Brahma Siddhānta* when he was only thirty years of age. If this indeed is his excuse we accept it and drop the matter."

¹ *Bṛihat Samhitā*, V, 17.

² See H. T. COLEBROOKE *Algebra...from Brahmagupta and Bhāscara*, 1817; SUDHĀKARA DVIVEDI *Brāhmasphuṭasiddhānta*, etc., 1902; and my *Indian Mathematics*, 1915, etc.

³ *India*, i, 156.

⁴ *Ib.*, ii, 110—112.

⁵ These are, apparently, his remarks on eclipses and his condemnation of Āryabhaṭa and others, which have already been quoted (§ 46).

Brahmagupta is perhaps the most distinguished of the Hindu mathematicians known to us and Albīrūnī appears to have considered him the most distinguished of the Hindu astronomers. He appears at the climax of the intellectual period of the Guptas and after his time no real advance was made in either mathematics or astronomy. Even in his time signs of the coming deterioration were not wanting. Brahmagupta himself was prepared to sacrifice truth on the altar of orthodoxy, and to the historian he is now famous rather for his vilification of Āryabhaṭa and others than as a leading astronomer.

The elements of his astronomy are given in appendix ii. There is nothing particularly noteworthy in his teaching: as he himself has said—the astronomical works of the period “differ only in words,” probably, however, with advantage to Brahmagupta. He refutes the rotation of the earth, upholds the orthodox explanation of eclipses, etc. He divides the ecliptic into 28 unequal nakshatras in the same manner as the *Sūryaprajñapti*. Besides the usual siddhāntas he refers to the Indu and to Yavana siddhāntas. He employs the epoch A.D. 665 in one of his later works.*

* The following note by Professor C. A. Nallino of Rome shows the influence of Brahmagupta and other Indians on Muhammadan writers. “The Muhammadans owe the first scientific elements of astronomy to India. In A.D. 771 there came to Baghdād an Indian embassy one learned member of which introduced to the Arabs the *Brāhmasphuṭasiddhānta* composed in Sanskrit in A.D. 628 by Brahmagupta. From this work (which the Arabs called *as-Sind-Hind*) Ibrāhīm ibn Ḥabīb al-Fazārī drew the elements and methods of calculation for his astronomical tables adapted to the Muhammadan lunar year. Almost contemporaneously Ya'qūb ibn Tāriq composed his *Tarkīb al-aflāk*, ‘The composition of the Celestial Spheres,’ which was based on the elements and methods of the *Brāhmasphuṭasiddhānta* and on other data furnished by another Indian scientist (K. n. k. h.), who came to Bagdad with a second embassy in 161 A.H. (A.D. 777-778). It seems that almost at the same time there was translated into Arabic under the name *al-Arkand* the *Khaṇḍakhādya*, written about A.D. 665 by the same Brahmagupta, but containing elements different from those of his other work. Abū'l-ḥasan al-Ahwāzī, a contemporary of al-Fazārī and of Ya'qub ibn Tāriq, probably drawing on oral teachings of learned Indians, introduced to the Arabs the planetary motions according to al-Arjabhad (a corruption of Āryabhaṭa, the name of an Indian astronomer who wrote in A.D. 500). These Indian works had many imitators in the Muhammadan world up to the end of the first half of the 5th century of the Hijra (11th cent. A.D.); some astronomers (e.g., Ḥabash, an-Nairizī, Ibn as-Samh) wrote contemporaneously books based on Indian methods and elements and books with Graeco-Arabic elements; others (e.g., Muḥammad ibn Ishāq as-Sarāḥsī, Abū'l Wafā', al-Bīrūnī, al-Ḥazīnī) adapted elements calculated by the Muhammadan astronomers to great artificial cycles of years constructed in imitation of those of the Indians.” (*ERE* xii, 95.)

CHAPTER VIII.

The astronomy of the second period.

49. As already pointed out there is a distinct break in continuity of ideas and methods between our two main astronomical periods. The new astronomy, with which we now have to deal, is altogether different from that already exhibited. The new Hindu astronomical school absorbed as much of the western teaching as they could, but the orthodox found themselves in somewhat of a quandary, for it was not always easy to square the new teaching with so much of the traditional cosmology and astronomy as had been incorporated with the popular religious teaching and ritual. Fortunately for the new teachers they had almost a 'clean slate'; but there were certain recorded notions, old enough to have become a real part of the intellectual universe of the people, some of which did not fit in very well with the new ideas.

Āryabhaṭa was, apparently, wholly progressive and was quite prepared to discard any tradition that did not fit in properly; but Brahmagupta and others preferred to make concessions to the ignorant and bigoted of their time; and although they did not allow the popular notions to interfere with their scientific work, they did not discard them altogether. We therefore have, mixed up with the new science, a fair number of rather incongruous notions that give to the whole scheme a somewhat fantastic appearance.

The astronomical treatises produced by the new school are fundamentally all constructed on the same plan, and as Brahmagupta pointed out, the differences are matters of detail or even of words only. Varāha Mihira has, in the introduction to his great astrological work, the *Bṛihat Saṃhitā*, given a conspectus of the astronomical knowledge of his time and this will also serve as a typical outline of the contents of an astronomical siddhānta of the period. Varāha Mihira writes:

"As to mathematical astronomy, he must know the divisions of heaven and of time, in ages, years, half-years, seasons, months, half-months, days, watches, muhūrtas, ghāṭis, palas, prāṇas, vipalas, prativipalas, etc., as taught in these five siddhāntas—the Paulīśa, Romaka, Vāsishṭhā, Saura and Brāhma siddhāntas. He must know the reason why there are four kinds of months—solar, sāvana, sidereal and lunar, and how it happens there are added months and subtractive days. He must know the beginning and end of the Jovian cycle of sixty years, of the cycles, years, days, hours, and their respective lords. He must be able to explain in what respect the reckoning after solar time shows similarity or difference compared with lunar, sidereal and sāvana reckoning of time and to what use each of these is adapted or not. And when there is a discrepancy between the siddhāntas he must be able to prove

experimentally, by means of the agreement between the shadow and the clepsydra, between observation and calculation, at what moment the sun has reached the solstitial point, and at how many ghaṭikas the sun enters the prime vertical. He must know the cause of the swift and slow motion, the northern and southern course, and the moving in an epicycle of the sun and the other planets. He must tell the moment of commencement and separation, the direction, measure, duration, amount of obscuration, colour and place of the eclipses of the sun and moon; also the future conjunctions and hostile encounters of the nine planets. He must be skilful in ascertaining the distance of each planet from the earth, expressed in yojanas; further the dimensions of their orbits, and the distance of the places on earth in yojanas. He ought to be clever in geometrical operations and in the calculation of time, in order to determine the form of the earth, the circle of the circuit of the asterisms, etc.; the depression of the pole, the diameter of the day circle, the ascensional differences in time, the rising of the signs, the ghaṭikas corresponding to the shadow of the gnomon, and such like processes."

50. GENERAL NOTIONS.—The earth is supposed to be an immovable sphere fixed at the centre of the universe, and around which the sun, moon and other planets revolve. It does not rotate, otherwise "falcons and other birds could not return from the ether to their nests," and "flags and similar things would, owing to the quickness of the rotation, stream constantly towards the west." Āryabhaṭa, however, taught that the earth did rotate, but his teaching on this point was altogether rejected. The path of the sun is divided into two equal parts, namely the period during which he is going towards the north, and the period of progressing southwards, or from solstice to solstice. The obliquity, it is implied, is 24 degrees. The order of the planets is correctly known, but, nearly always, they are placed in the week-day order. They are supposed to move with equal velocities of approximately 1,200 yojanas a day. Eclipses are caused by the demon Rāhu (*Caput Draconis*), whose head corresponds, astronomically, to the moon's ascending node; but Āryabhaṭa and Varāha Mihira taught more correct views. The only stars noticed are the yogatārās or 'junction stars,' of the nakshatras, and Canopus and Sirius. The sphere of the stars is driven by a wind (*pravaha*). Precession was possibly known and in comparatively late works was explained as a libration, but as an astronomical phenomenon of importance was practically ignored; and the difference between the tropical and sidereal year is not noticed. According to Varāha Mihira¹ "the appearance and disappearance of comets (*ketu*, ? meteor) is not subject to astronomical calculations."

51. THE EARTH.—The diameter of the earth is given as 1,600 yojanas and its circumference as $1,600\sqrt{10}$. The prime meridian passes through Lankā and Ujjain, the latter being placed on the tropic of Cancer, and its longitude being given as 44 degrees east of Yavanapura.

¹ *Bṛihat Saṃhitā*. xi, 2.



Mount Meru, the abode of the gods, is identical with the north pole. The length of the day at Meru is six months and there the sun never rises higher than 24 degrees.

Terrestrial coordinates.—Terrestrial longitude (l) is measured by the distance in yojanas from the prime meridian. If c is the circumference of the earth at the equator and c_φ the circumference at latitude φ , then $c_\varphi = c \cdot \cos \varphi$

and l' degrees $= \frac{360 l}{1,600 \sqrt{10 \cos \varphi}}$. To determine the difference in longitude directions are given for recording the time of emergence at a lunar eclipse; but the only real record is 10 degrees difference between Benares and Ujjain, whereas the actual difference is about $7^\circ 14'$.

Theoretically, terrestrial latitude, also recorded in yojanas, was determined by the length of the equinoctial noon-day shadow (e) of a vertical gnomon (g), that is $\tan \varphi = e/g$, but the only record is 24° N. for Ujjain and this is at least $1\frac{1}{2}$ degrees too much. Since the obliquity was considered to be 24 degrees, theoretically there was no equinoctial noon-day shadow at Ujjain. The length of the day was known to vary with the latitude as well as the time of the year and various rules were given. (See § 71.)

52. THE PRIME MERIDIAN.—According to the *Pañchasiddhāntikā* (xv. 18-23) the early authorities were not in agreement as to the position of their prime meridian. The choice lay between (a) Yavanapura (Alexandria) (b) 180 degrees from the meridian of the Yavanas (Greeks) and (c) Laṅkā. The position of Laṅkā is defined as being on the same meridian as Ujjain,¹ "which is near to Laṅkā, being situated to the north on the same meridian. Laṅkā is on the equator, for the people there "see the pole star on the horizon". The statement is often made that sunrise in Laṅkā is sunset in Siddhapura, is midday in Yamakoti, midnight in the Romaka country;² and the *Pañchāsiddhāntikā* points out that the longitude of the Romaka country differs from that of Yavanapura. The identification of Yamakoti is uncertain. Albīrūnī writes: "Yamakoti (90° E. of Laṅkā) is, according to Yakub and Alfazāri, where is the city Tāra within a sea." "I have not found" he continues, "the slightest trace of this name in Indian literature. As *koṭi* means 'castle' and Yama is the angel of death, the word reminds me of Kangdiz, which according to the Persians, had been built by Kaikā'ūs or Jam in the most remote east, behind the sea.... Abū-Ma'shar of Balk has based his geographical cannon on Kangdiz as the zero of longitude or first meridian." "How the Hindus," he goes on to say, "came to suppose the existence of Siddhapura (180 from Laṅkā) I do not know for they believe, like ourselves, that behind the inhabited half circle there is nothing but unnavigable seas."

¹ The difference between the longitude of Laṅkā (in Ceylon) and Ujjain is at least four degrees. This discrepancy has been explained away by some ingenious writers by the suggestion that Ceylon was originally much larger than it is now. Laṅkā is sometimes identified with the island itself, but certain Northern Paṇḍits have denied that it is connected with Ceylon at all.

² That is: the Romaka country is 90 degrees west of Laṅkā, Yamakoti is 90 degrees east, while Siddhapura 'the abode of the blest') is 180 degrees distant.

The term Siddhapura means 'the city of the perfected' and according to the *Sūrya Siddhānta*, (xii. 40) "in it dwell the magnanimous perfected free from trouble." There can be little doubt that the 'Fortunate Isles,' where the souls of the good were made happy and from which the Greeks counted their longitude, are meant.¹

53. CELESTIAL COORDINATES.—For bodies on or near the ecliptic ordinary celestial longitude was used, or may be considered to have been used. No definitions are given in the early works and the methods are exceedingly crude. For example, in the *Pañchasiddhāntikā* the two stars of Punarvasu, or α and β Geminorum are given the same longitude and latitude. To express the latitude of a star its distance in *aṅgulas* or digits from the ecliptic or from the centre of the moon was given, the moon's diameter being divided into 15 *aṅgulas*. Apparently the moon's latitude was considered negligible for this purpose.

Later the coordinates used for defining the position of stars were the ecliptic and the great circle passing through the poles of the equator (i.e., a declination circle) and ζ Piscium. This longitude (λ') is then the part of the ecliptic intercepted between ζ Piscium and the point of intersection of the declination circle passing through the star and the ecliptic. The corresponding latitude (β') is the part intercepted on the same declination circle between the star and the ecliptic. Whitney called λ' and β' the *polar* longitude and latitude.² (See also §67c.)

THE FIXED POINT.—All the later Hindu texts agree in regarding the star ζ Piscium or 10' east of that star as the point of origin for longitude and similar calculations, and to the present day it is supposed to mark a sort of artificial vernal equinox and the commencement of the year.

The star ζ Piscium was within a degree of the equinoctial point at A.D. 505 (Śaka 427), the epoch used by Varāha Mihira. According to Bhāskara the coincidence took place in A.D. 527, while Whitney calculated A.D. 570.³ The *Pañchasiddhāntikā* says: "At the present time (A.D. 505) the *ayana* begins from Punarvasu" and this means that the sun's southern course commenced, or in other words, the summer solstice took place, when the sun entered the nakshatra Punarvasu. This conveys no very precise meaning, for Punarvasu occupies some $13\frac{1}{2}$ degrees and it commences at an indefinite distance from some point that is now unknown and probably never was fixed with any exactitude. But according to one scheme Punarvasu corresponds roughly to α and β Geminorum, and within the general range of accuracy

¹ According to the Arabs the longitudes of the 'Fortunate Isles' must have been about 35 degrees west of Greenwich, and thus about 115 degrees west of Ceylon; but the *Pañchasiddhāntikā* (xv. 19) seems to indicate that the prime meridian of the Yavanas was 180 degrees from Latkā.

² Abū 'Alī al-Hasan (13th century) employed the so-called polar longitudes, and so did Jai Singh in the 18th century. See my *Astronomical Observatories of Jai Singh*, p. 8.

³ JAOS, 1858, p. 158. In 1918 ζ Piscium was about 18 degrees from the true vernal equinoctial point. The Hindu year then commenced on April 12th, while spring actually commenced on March 21 d. at 10 h. 26 m.

of the text, the summer solstice marked by Punarvasu corresponds to the vernal equinox at ζ Piscium. There is, however, little doubt that at this period (A.D. 505) and for a considerable time afterwards the necessity for a fixed zero point was not realized; although it may have been known that the positions of the solstices changed.

54. ANGULAR UNITS OF MEASUREMENT.—Strictly speaking angular measurements were not employed at all. They appear almost to have been systematically avoided; and when the Greeks, for example, gave an angular measurement the Hindus gave a length. Whitney pointed out¹ many years ago that in the *Sūrya Siddhānta* at least the Hindus “made no use whatever in their calculations of the angle.” The nearest approach to a real angular quantity was possibly the Saura day. But they introduced the usually Greek nomenclature of ‘sign’ (*rāśi*), ‘minute’ (*liptā* or *kalā*), ‘second’ (*vikalā*). In the Vedāṅga period, however, these do not occur—the nakshatra (=800′) and the *aṁśa*, of which 124 went to the nakshatra, being employed.

Signs.—The names of the western zodiacal signs—Aries, Taurus, etc.—were introduced with a double signification, namely as designating particular portions of the ecliptic and as measures of any arc.

Degrees, etc.—The term for degree is *bhāga* or *aṁśa*, and each of these words, like the original Greek word *μωρα* means a ‘part’ or ‘fraction.’ The minute of arc is *liptā* (Gk. $\lambda\epsilon\pi\tau\omicron$) or *kalā*, and this division appears to have been preferred to the degree, for nearly all the actual measurement recorded are in minutes, as lengths of arc. The second of arc is *vikalā* or *viliptā*.

Digits.—The digit (*aṅgula*) is employed in the theory of the gnomon and in measuring the diameter of the moon, particularly in eclipses. The history of the digit as an astronomical unit of measurement is obscure.² The *Pañcha-siddhāntikā* seems to imply that it was one-fifteenth of the moon’s diameter, while the *Sūrya Siddhānta* seems to make it one-twelfth, and on another occasion equal to 4 minutes of arc.³

The vertical gnomon was usually divided by the Hindus into 12 *aṅgulas* or digits, but in later times 12 *daṇḍas* or 720 minutes was sometimes the division employed.

The term *daṇḍa* denotes usually a measure of length equal to 96 digits or about 6 feet; but it also was used as an equivalent for a *nāḍī* (24 minutes). The earliest Hindu record of measurements of star places employs degrees for the measurement in longitude and *hastas* for latitude. Usually 4 *hastas* are equivalent to one *daṇḍa* but in these star measurements possibly the *hasta* denotes 48 minutes of arc and, since 24 digits equal a *hasta* each digit would then denote 2 minutes.

Tables of sines.—The *Paulīśa Siddhānta* gives a table of twenty-four sines which appear to have been obtained from Ptolemy’s table of chords. Instead,

¹ JAOS, 1858, p. 259.

² See P. TANNERY, *Mémoires*, ii, 256 et seq.

³ PS, xiv, 38 : SS, iv, 9 and 26, and x, 9.

however, of dividing the radius into 60 parts as did Ptolemy, Pauliśa divided it into 120 parts; for as $\sin \theta = \frac{\text{chord } 2\theta}{2}$ this division of the radius enabled him to utilise the table of chords without numerical change. Āryabhaṭa gives another measure for the radius (3438') which enabled him to express the sines in a sort of circular measure, while Brahmagupta divided the radius into 3270 parts. The several stages are—

- (i) The chords of Ptolemy with $r=60$
- (ii) The sines of Pauliśa with $r=120$
- (iii) The sines of Āryabhaṭa with $r=3438$
- (iv) The sines of Brahmagupta with $r=3270$

Denoting these several sine functions by $\sin P$, $\sin A$, $\sin B$ we have $\sin I = \text{h'd } 2\theta$, $\sin A = \frac{3}{\pi} (\frac{1}{2} \text{ ch'd } 2\theta)$, $\sin B = \frac{3}{\pi} (\frac{1}{2} \text{ ch'd } 2\theta)$ where B , A , B and θ are the same arcs. In forming his table Āryabhaṭa appears to have used the approximately correct value $\pi = 600/191$, while Brahmagupta seems to have employed some convenient though rough approximation near to the value $3\frac{1}{2}$, realising that this approximation in no way vitiated his table.¹

In the *Pañchasiddhāntikā* the Pauliśa sines are generally used, while in most of the later works the sines of Āryabhaṭa are used. The tables of sines are given in appendix iii (table 11). See also §65.

TIME.

55. The Hindu astronomers developed a curious time system. Since, in practice, they ignored precession they made no differentiation between the tropical and sidereal year. In the *Jyotiṣa Vedāṅga* their astronomy almost wholly consists of sidereal calculations but later, except in the case of the year, sidereal units do not seem ever to have been freely employed. Their principal real units were the *sāvāna* or 'civil' day and its subdivisions, and the year; but they introduced at a comparatively late date, the so-called lunar day or *tithi*, of which thirty make a synodic month, and this became to a great extent their basis of reckoning.

In nearly all their works are found two sets of measures, one of which was actually used, while the other consists of units that at first appear to have been created simply to satisfy flights of imagination. It is not always easy to distinguish these two sets, but we can, for example, class as artificial the *para* of 311,040,000,000,000 years and the *truṭi* of about 00003 seconds. At present we are concerned only with such units as were actually employed for astronomical purposes.

¹ If the radius be expressed in terms of the length of the circumference (in degrees) we have $r = 360^\circ/2\pi = 57.2958$ degrees = 3437.75 minutes approximately. How Brahmagupta arrived at 3270 is not certain. As suggested above his value for π may have been a rough one: but it may also be noted that $3270 = (57.184)^\circ$ or $120 \times 27\frac{1}{2}$.

The modern *Sūrya Siddhānta* points out (xiv. 2) that practical use is made of four kinds of time, namely solar, lunar, sidereal and civil (*sāvana*) time. Of these the so-called 'solar' and 'lunar' are not strictly direct measures of time but of arc, or rather angular motion, and are obtained by dividing the period of revolution by the angular measure of the path of revolution. They seem to correspond to the time degrees of Hypsicles.¹ The actual unit of solar time is the solar day which is obtained by dividing the length of the year by 360; and the unit of lunar time is the *tithi*, which is the synodical month divided by 30. Civil or *sāvana* time is based upon the day reckoned, generally, from sun-rise to sun-rise.

The uses of the different measures of time, according to the *Sūrya Siddhānta* (xiv. 3—18), are as follows:—

Solar time.—"The measure of day and night, the *śaḍaśītimukhas*,² the solstice, the equinox, and the propitious period of the sun's entrance into a sign—are determined by solar time."

Lunar time.—"General ceremonies, marriages, shaving, and the performance of vows, fastings and pilgrimages, are determined by lunar time."

Civil time.—"The time of sacrifice, the regents of days, the mean motions of the planets, etc., are determined by *sāvana* time."

DAYS.

56. *The sāvana day.*—The fundamental unit was the *sāvana* or civil day, reckoned generally from sun-rise to sun-rise,³ and treated as a constant quantity. Brahmagupta defines the *sāvana* day as an 'earth' day, possibly in contradistinction with the so-called solar day. The *sāvana* day, for practical purposes, corresponds to what we call the mean solar day. The subdivisions commonly employed are as follows:

Subdivisions of the day.⁴

	1 vipala ⁵.	.	.	.	.	0·4 second.
10 vipalas	= 1 prāṇa .	.	.	.	.	4 seconds
60 vipalas	= 1 pala .	.	.	.	.	24 "
2 palas	= 1 kalā .	.	.	.	.	48 "
60 palas	= 1 ghaṭī .	.	.	.	.	24 minutes.
2 ghaṭīs	= 1 muhūrta .	.	.	.	.	48 "
60 ghaṭīs	= 1 day ⁶ .	.	.	.	.	24 hours.
30 muhūrtas	= 1 " .	.	.	.	.	24 "

¹ DELAMBRE 1,248. A similar case occurs in the *Sūryaprajñapti*, where the ecliptic is expressed in terms of the sidereal month. See § 24.

² The term *śaḍaśītimukha* is an astrological one connected with the subdivision of signs into novenaries.

³ The practice seems to have varied to some extent. The *Romaka Siddhānta* reckoned from sunset to sunset (PS I, 8), and this was also the practice of Laṭa (PS xiv, 18—19). Śimbhāchāraya reckoned from sun-rise and Brahmagupta established that practice.

⁴ The apparent solar day (noon to noon) varies in length up to a little more than three-quarters of a minute. Reckoned from sun-rise to sun-rise the variation would generally be greater.

⁵ Alternative terms are *gurvākshara* for *vipala*, *vināḍī* for *pala*, *nāḍī* for *ghaṭī*, *kahana* for *muhūrta*, &c.

⁶ According to the *Sūrya Siddhānta* (i, 12) a sidereal day.

THE TITHI.—Thirty *tithis* make a synodic month and a *tithi* is defined as the period in which the difference in longitude between the moon and the sun increases by 12 degrees. It varies in length from about 21 h. 34 m. 24 sec. to 26 h. 6 m. 24 sec. A *sāvāna* day (24 hours) may therefore include a whole *tithi* and parts of two others and a *tithi* may 'touch three civil days.' This necessitates the suppression of some 13 *tithis* in 12 synodic months and the repetition of some 7 *tithis* in the same period. There are, however, indications in the early *siddhāntas* that the variation in the length of the *tithi* was not noticed, or was not considered of sufficient importance to affect the calculations.

The *tithi* appears comparatively late in Hindu literature. It is completely unknown in the *Brāhmaṇas*, but the name occurs in the later *Sūtras*.¹ In the *Jyotiṣa Vedāṅga* the *tithi* certainly is not of importance but a knowledge of it is implied. The earliest definition appears to occur in the *Paulīśa Siddhānta* (PS. ii. 7 and xiv. 12). From the *Romaka Siddhānta* onwards, however, the *tithi* is an essential part of each system which is epitomised by stating (a) the number of years, (b) the additional months and (c) the omitted *tithis* in a *yuga* or cycle.

The origin of the *tithi* is somewhat obscure. As a time unit it is most extraordinary, and possibly it originated as an angular measurement of motion, like the solar day.

The solar day.—The so-called solar day, which is really not a time unit but an angular measure, is hinted at in the *Jyotiṣa Vedāṅga*, is employed in the *Pañchasiddhāntikā* and is largely used by *Paulīśa*.² It is obtained by dividing the length of the year by 360.

The sidereal day.—The sidereal day is defined as a revolution of the circle of the stars. The subdivisions of the day are said to be based upon the sidereal day, but in practice they generally pertain to the *Sāvāna* day.

The lunar day.—A day reckoned from moon-rise to moon-rise is referred to in the *Jyotiṣa Vedāṅga* and the number of the risings of the moon in the cycle of five years is given as 1768 ($=5 \times 366 - 62$), and this lunar day was therefore equal to $1 + 31/884$ *sāvāna* days. With the coming of Greek astronomy it appears to have dropped out of use.

MONTHS.

57. The solar month is the time the sun takes to traverse a sign of the zodiac, and was probably at first considered as consisting of 30 solar days; but the *Paulīśa Siddhānta* points out the irregularity of the sun's motion and gives the average daily motion for the several months as 57', 57', 57', 57', 58', 59', 61', 61', 61', 61', 60', 59'.

In the *Jyotiṣa Vedāṅga* the time of the sun in each *nakṣatra* was employed as a unit, but the *nakṣatra* scale was later on, partly, at least, replaced by the scale of signs.

¹ *Gobhila Gṛihya Sūtra*, i, 1¹²; ii, 8¹², 20; *Saṅkhayāna Gṛihya Sūtra*, . 25; v, 2. etc.

² *AL-BIRŪNĪ India*, ii, 41 et seq.

The term *saura*, or solar, month is an awkward one but the measure it denotes, i.e., the time the sun remains in a sign, is a scientific one, and became important in the later works. The months were eventually named after twelve selected nakshatras (or *vice versâ*) and an attempt was made to explain the genesis of these names by connecting them with the moon. The usual explanation is as follows:

"The full moon which occurred when the moon was in conjunction with Chitrâ was named Chaitrî, and the lunar month which contained the Chaitrî full moon was named Chaitra, and so on with the others." A possible explanation, that agrees with the traditional one to a certain extent, is that the nomenclature represents an attempt to equate the nakshatras and signs of the zodiac. In later times the name of the month is determined altogether by the position of the sun with reference to the zodiacal signs.

The synodic month.—The synodic month is variously reckoned from new moon to new moon, and is then termed *amānta*, or *śuklādi*; or from full moon to full moon and is then termed *pūrṇi mānta* or *krishṇādi*. It forms one of the most important of the *siddhānta* elements; but in later practice it is subordinated to the *saura* month, on which it is always made, more or less, dependent. The lunar Chaitra may be defined as the *amānta* month at the first moment of which the sun is in the sign *Mina* (Pisces) and in the course of which the sun enters *Mesha* (Aries).

The synodic month is divided into two portions (*paksha*) called the bright half (*śukla*, *śuddha*, etc.) and the dark half (*krishṇa*, *bahula*, etc.). The bright half ends at full moon and the dark half is from full to new moon.

INTERCALATION.—Since a solar month varies from about 29 d. 7 h. 38 m. to about 31 d. 15 h. 28 m. and a synodic month from about 29 d. 7 h. 20 m. to 29 d. 19 h. 30 m. it is possible for two synodic months to fall partly within one solar month, and also for two solar months to fall partly within one synodic month. In the former case an additional synodic month (*adhimāsa*) is intercalated; while in the latter case a synodic month is suppressed. There are normally 7 *adhimāsas* intercalated in 19 years, while one month is suppressed at intervals of about 19 years. The suppression of a month is probably a comparatively late refinement.

The early texts give the number of *adhimāsas* or months to be intercalated in a cycle, but make no reference to suppressed months, nor do they notice the variation in the length of the synodic month; and, although they record roughly the variation in the length of the solar month, they do not appear to have troubled much about it for calendar purposes.

THE SIDEREAL MONTH.—The sidereal month is mentioned in the early astronomical texts and in the *Sūryaprajñapti* it is employed as the basis of the nakshatra scale; but it does not appear to have been made much account of in any Hindu method of reckoning time.

The lengths of the synodic and sidereal months (in *sāvāna* days) given in the several texts are as follows:

Authority.	Synodic month.	Sidereal month.
	Days.	Days.
Jyotisha Vedāṅga	$29\frac{1}{2} = 29.5161$	$27\frac{1}{4} = 27.31$
Kautilyās Arthaśāstra	$29\frac{1}{2} = 29.5000$	.....
Romaka Siddhānta	29.52037	27.321601
Old Sūrya Siddhānta	29.530587	27.321673
Pauliśa Siddhānta	29.530587	27.321673
Āryabhaṭa	29.530582	27.321668
Brahmagupta	29.530582	27.321668
Later Sūrya Siddhānta	29.530879	27.321674
Bhāskara	29.530587	27.331139
Approximately correct values	29.530588	27.321661

58. THE YEAR.¹—The year was originally tropical but with the first formal works on astronomy became sidereal. The difference between the tropical and sidereal year is generally ignored. Of the so-called lunar year of twelve lunar months “We know of no use made in India, either formerly or now, except as it has been introduced or employed by the Mohemmadans” writes Whitney.

At the period of the introduction of Greek astronomy the year began when the sun was near ζ Piscium which then nearly coincided with the vernal equinox. This is usually termed the *Mesha saṁkrānti*, which means ‘the entrance (of the sun) into the sign Aries.’ The year is still counted from the conjunction of the sun with the same star, and this conjunction is considered as a sort of artificial vernal equinox.

The length of the year employed for calendar purposes differs slightly in different parts of India and the civil year begins at various times and the first civil day is also determined by various methods.

The year is still divided into the *uttarāyana*, or period during which the sun is moving northwards, and *dakṣiṇāyana*, or period during which it is moving south. The *uttarāyana* does not now begin at the time of the real winter solstice but at the nominal one (about January 12th) and similarly the commencement of the *dakṣiṇāyana* is displaced.

¹ See also §28.

The various lengths of the year employed are:

Period circa.	Authority.	Length.
	Vedas	360 (But see § 28, page 26).
	Jyotisha Vedāṅga, etc. .	366.
A.D. 400 to 500	Pauliśa siddhānta	365 d. 6 h. 12 m. 36 sec. = 365-25875 Sidereal.
	Old Sūrya siddhānta . . .	365 d. 6 h. 12 m. 36 sec. = 365-25875 „
	Romaka siddhānta	365 d. 5 h. 55 m. 12 sec. = 365-2466 Tropical (Hipparchus).
A.D. 500	Āryabhaṭa	365 d. 6 h. 12 m. 30 sec. = 365-25868 Sidereal.
A.D. 628	Brahmagupta	365 d. 6 h. 12 m. 9 sec. = 365-25844 „
	Later Ārya siddhānta . . .	365 d. 6 h. 12 m. 30-8 = 365-25869 „
A.D. 1150	Bhāskara	365 d. 6 h. 12 m. 9 = 365-25844 „
	Later Sūrya siddhānta . . .	365 d. 6 h. 12 m. 36-56 = 365-25876 „
A.D. 1917	Modern Brahma siddhānta.	365 d. 6 h. 12 m. 30-9 = 365-25869 „
	Approximately correct values.	365 d. 5 h. 48 m. 45-98 = 365-242199 Tropical.
		365 d. 6 h. 9 m. 9-5 = 365-256360 Sidereal.

59. CYCLES OR YUGAS.—The evolution of the cycle or period of time (*yuga*) employed as a sort of major astronomical unit by the Hindus is fairly definitely outlined. We have the following order:—

Cycle.	Text.	Period.
5 years	Jyotisha Vedāṅga	Up to about A.D. 200. The Paitāmaha siddhānta uses the epoch of A.D. 80.
	Arthaśāstra	
	Sūryaprajñāpti	
	Paitāmaha siddhānta	
2,850 years	Romaka siddhānta	A.D. 400
180,000 years	Early Sūryasiddhānta . . .	„
1,050,000 years . . . . .	.....	.....
4,320,000 years	Later siddhāntas	A.D. 500 onwards.
4,320,000 000 years	Brahmagupta, etc.	A.D. 628 „

It may be noted that $4,320,000 = 20.60^3$; $1,080,000 = 5.60^3$; $180,000 = 50.60^3$; $2,850 = 19 \times 50$. This last suggests a connexion with the Metonic cycle, and this suggestion is supported by the fact that the *Romaka Siddhānta* also employs the tropical year of Hipparchus.

None of the cycles is of great antiquity in India¹—all, except perhaps the five year cycle, were imported with the western astronomy, but their history is not very clear. The Greeks had successively employed cycles of 8, 16, 19 (Meton), 59 (Oenopidus), 76 (Calippus), 2,484 (Aristarchus), 304 (Hipparchus), 10,800 and 180,000 (Heraclitus), 120,000 (Orpheus), 360,000 (Cassandrus); and the Chaldean cycle was 432,000 years. The Greeks sought a period without fractions (*exeligmos*) and so did the Hindus.² The earlier and smaller cycles were attempts at reconciling the motions of the sun and moon only. Later the planets were brought into the scheme and the cycles naturally became greater (1,080,000 years) and later still the revolutions of the apsis and node of the moon being included necessitated a still greater number (4,320,000 years); and later still the inclusion of the supposed revolutions of the apses and nodes of the other planets involved the still greater cycle of 4,320,000,000 years.

The subdivisions and multiples of the *mahāyuga* of 4,320,000 years have little astronomical value. Āryabhaṭa and Brahmagupta differ as to details and, on this matter Brahmagupta, as representing the orthodox, condemns Āryabhaṭa.

—	Āryabhaṭa.	Brahmagupta.	
	Periods.		
1st Yuga pāda . . .	$1,080,000 = 5.60^3$	$1,728,000 = 8.60^3$	Kṛita.
2nd „ . . .	$1,080,000 = 5.60^3$	$1,296,000 = 6.60^3$	Treta.
3rd „ . . .	$1,080,000 = 5.60^3$	$864,000 = 4.60^3$	Dvāpara.
4th „ . . .	$1,080,000 = 5.60^3$	$432,000 = 2.60^3$	Kali.
Mahāyuga or Chaturyuga .	$4,320,000 = 20.60^3$	$4,320,000 = 20.60^3$	Mahāyuga or Chaturyuga.
Manvantara . . .	$72 \times 4,320,000 = 311,040,000 = 24.60^4$	$71 \times 4,320,000 = 306,720,000 = 71.(20.60^3)$	Manvantara.
Kalpa . . .	$14 \times 311,040,000 = 4,354,560,000 = 336.60^4 = 1008 (20.60^3)$	$14 \times 306,720,000 + 15 \times 1,728,000 = 4,320,000,000 = 1000 (20.60^3)$	Kalpa.

¹ The *Mahābhārata* (iii, 188) refers to the *mahāyuga*. Aśoka speaks of 'the kalpa of destruction,' and an inscription of A.D. 150 mentions the end of the yugas. See J. F. FLEET, JRAS, 1911, p. 455. See also p. 26.

² See P. TANNERY. *Le grand année d'Aristarque de Samos*. Mémoires scientifiques. ii. 540; also DILLMANN's analysis of the chapter from Geminus 'Peri exeligmos.' *Histoire de l'astronomie ancienne*, i, 297; FLEET JRAS, 1911, 479 et seq.

Brahmagupta gives another variation which makes a *kalpa* 994 times a *mahāyuga*. Also there is a further extension employed called the *mahākalpa* or half the life of Brahma, equal to 100×360 kalpas = 155,520,000,000,000 years.

We are supposed now to be in the Kaliyuga of the 28th Chaturyuga in the 7th Manvantara in the first Kalpa in the second half of the life of Brahma.

60. EPOCHS.—The Hindu astronomers were not observers but calculators. Their text-books gave the necessary elements, and to find the positions of the planets at any particular time they did not make and record observations and calculate from such observations, but calculated from a given epoch the places the planets should occupy. Varāha Mihira gives as the working epoch for the *Paitāmaha Siddhānta*, Śaka 2 = A.D. 80, and for the *Romaka Siddhānta* Śaka 427 = A.D. 505. Brahmagupta employs A.D. 665. The modern *Sūrya Siddhānta* actually works from the beginning of the Kali yuga, or 3102 B.C., while it and other texts also appear to work from the beginning of the Kalpa or even from their estimated period of creation, or nearly two thousand million years B.C.

The following dates occur:—

Kaliyuga .	0 ¹ = B.C. 3101 = 3,240,000 of the chaturyuga.		
Śaka .	0 = A.D. 78 = 3,243,179	„	„
	2 = „ 80 = 3,243,181	„	„
	427 = „ 505 = 3,243,606	„	„
	587 = „ 665 = 3,243,766	„	„
	953 = „ 1031 ² = 3,244,132	„	„

The *ahargana*.

61(a). The term *ahargana*, or 'sum of days' refers to a method of calculating, by means of the number of years, intercalary months and omitted tithis in a yuga, the number of civil or *sāvana* days that have elapsed from a certain period, when the years, months and tithis, in which dates are generally expressed, are known. The years are either sidereal or tropical (the difference being ignored); the months are marked by the entry of the sun into the successive signs; and the tithis are one-thirtieth parts of the synodic month.

The texts give the years (Y) in a cycle, the intercalary months (M_i) in a cycle, and the omitted tithis (D_o) in a cycle as the essential elements; and from these the other elements can be deduced as follows:—

Solar months	M _i = 12Y
Synodic months	M _i = 12Y + M _i
Sidereal months	M _s = M _i + Y
Solar days	D _i = 30M _i
Tithis.	D _i = 30M _i
Sāvana or civil days	D = D _i — D _o

¹ The Kaliyuga began at sunrise at Ujjain on Friday, 18th February 3102 B.C., according to some authorities; according to others at the preceding midnight.

² Albirūnī's gauge year, Thursday, 25th February = A.H. 422, 28th Safar.

If we express the yuga or cycle elements by capital letters (as above) and the elements for any given time by small letters we have

$$\frac{m_i}{m_s} = \frac{M_i}{M_s}; \quad \frac{d_i}{d_s} = \frac{D_i}{D_s}; \quad \frac{d_i}{m_i} = \frac{D_i}{M_i}; \quad \frac{d}{y} = \frac{D}{Y}; \text{ etc.}$$

(b) *Pulisa's method of division*.—Pulisa, who appears to be the chief authority in these calculations, employs the following method of division: If

$$\frac{A}{B + c/d} = \frac{A - x}{B} \text{ then } x = \frac{A c/d}{B + c/d} \text{ and } \frac{A}{B + c/d} = \frac{A - \frac{A c/d}{B + c/d}}{B}.$$

For example—

$$\begin{aligned} \text{i.} \quad & \frac{A}{976 \frac{104,064}{1,593,336}} = A - \frac{104,064 A}{1,593,336 \cdot 976} = A - \frac{104,064}{976} \frac{A}{1,593,336} = A - \frac{271 A}{976} \frac{1}{4,050,000}; \\ \text{ii.} \quad & A \frac{63379}{69673} = \frac{A - A/111,573 \frac{11}{439}}{703/11} \end{aligned}$$

(c) *Ahargana without kshapa*.—If the time that has elapsed since the beginning of a yuga or cycle is expressed by y years m' months and d_i' tithis then (i) $m_s = 12y + m'$, (ii) $m_i = \left[m, \frac{M_i}{M_s} \right]$, where the square bracket denotes that the quotient only is to be taken, (iii) $m_i = m_s + m_s$, (iv) $d_i = 30m + d_i'$, (v) $d_s = \left[d_i, \frac{D_i}{D_s} \right]$, (vi) $d = d_i - d_s$.

Example.—At the commencement of Śaka 953 (A.D. 1031 February 25th) 3,244,132 years of the chaturyuga had passed, and (i) $m_s = 12 \times 3,244,132^{\text{years}}$ (ii) $m_i = \left[\frac{12 \times 3,244,132 \times 1,593,336}{51,840,000} \right]^{\text{adhikmas}}$ (omitting the fractional portion), (iii-iv) $d_i = 30 (12 \times 3,244,132 + 1,196,525) = 1,203,783,770$,

(v) $d_s = \left[\frac{1,203,783,270 \times 25,082,252}{1,603,000,080} \right]^{\text{omitted tithis}} = 18,835,679$, (vi) $d = 1,203,783,270 - 18,835,679 = 1,184,947,591$ savana or civil days.

(d) *Brahmagupta's rule for the epoch śaka 587 (= A.D. 665)*.

(i) $d_s = 30 (12 (y \ 587) + m) + d_i'$, the days of the date being expressed in solar days (a curious point).

$$\text{(ii)} \quad m_i = \left[\frac{d_s + 5 - (d_i + 5) / 14945}{976} \right].$$

$$\text{(iii)} \quad d_i = 30 m_i + d_s$$

$$\text{(iv)} \quad d_s = \left[\frac{11 d_i - (11 d_i + 497) / 111,573}{703} \right].$$

$$\text{(v)} \quad d = d_i - d_s$$

¹ The following ratios are employed in the examples below:—

$$\frac{M}{D_s} = 63 \frac{63379}{69673}; \quad \frac{D_s}{Y} = 5 \frac{7739}{9600}; \quad \frac{D_i}{M_i} = 976 \frac{104064}{1593336}; \quad \frac{D}{Y} = 365 \frac{2481}{960}$$

See appendix iii, 4, p. 120.

The quantities 5 and 497 are added in on account of the epoch. At 587 S'. the calculation for the intercalary months gives a fraction of $\frac{5}{976}$, and that for omitted tithis gives a fraction $\frac{497}{703}$. Schram's calculation for the epoch is as follows: at the beginning of 587 Śaka 3,243,766 years of the chaturyuga had elapsed, and

$$\begin{aligned}
 (i) \quad d_s &= 360 \times 3,243,766 = 1,167,755,760. \\
 (ii) \quad \frac{271 \times 1,167,755,760}{4,050,000} &= 78,138 \frac{4043}{5625} \text{ and } \left[\frac{1,167,755,760 - 78,139}{976} \right] = 1,196,391 \frac{5}{976}. \\
 (iii) \quad 1,177,755,760 + 30 \times 1,196,391 &= 1,203,647,490. \\
 (iv) \quad \frac{11 \times 1,203,647,490}{1,113,573} &= 118,667 \frac{89,199}{111,573} \text{ and } \left[\frac{11 + 1,203,647,490 - 118,668}{703} \right] = 18,833,575 \frac{497}{703}. \\
 (v) \quad 1,203,647,490 - 18,833,575 &= 1,184,813,915^* \\
 (e) \quad \text{Brahmagupta's method for adhimāsas.} &\text{—For } y \text{ years we have} \\
 (i) \quad m_s &= \frac{360 y}{30} \\
 (ii) \quad m_i &= \frac{y}{30} \left(\frac{d + d_0}{y} \right) \\
 (iii) \quad m_1 = m_i - m_s &= \frac{y}{30} \left(\frac{d}{y} + \frac{d_0}{y} - 360 \right) = \frac{y}{30} \left(365 \frac{2481}{9600} + 5 \frac{7739}{9600} - 360 \right) = \frac{1}{30} \\
 (10 y + \frac{2481 y}{9600} + \frac{7739 y}{9600}) &\text{ which represents the rule given in the text.}
 \end{aligned}$$

The above examples indicate the methods employed, but they are not exhaustive. The practice varied and the texts are rather unsatisfactory. Apparently the *Romaka Siddhānta* is the earliest text which gives such elements as D, M, and D₀ and the *ahargaṇa* process. "This," Varāha Mihira says, "is the method of the siddhānta of the Greeks."

62. PRECESSION.¹—It has already been pointed out (§ 53) that the initial point of the Hindu celestial sphere is now considered as fixed at a point near ζ Piscium; but Varāha Mihira relates that, while in his time the summer solstice took place in Punarvasu (? α and β Geminorum), formerly it had taken place in the middle of Āśleṣha (? η Hydræ) and was then correct. This statement was made to elucidate an astrological rule² relating to certain aspects which are said to occur when $(\lambda_m - 23^\circ 20') + (\lambda_s - 23^\circ 20') = 0$ or 180° and the rule and explanation imply that the amount of precession during the period was one and

§ See (b) i.

* See (b) ii.

* Note that $d = 3,243,766 \frac{D}{Y} = 1,184,813,914.45$ where $D = 1,577,917,800$ and $Y = 4,320,000$.

¹ Precession was also dealt with in paragraph 31, to which reference should be made.

² P.S. III, 20-21. Also PS iii, 1-2, where he substitutes 'the beginning of Cancer' for Punarvasu.

two thirds nakshatras or $23^{\circ} 20'$. Immediately afterwards Varāha Mihira says: "When the degrees of the ayana are in the opposite direction, the quantities to be added to the sun's and moon's longitude equals the sun's maximum declination." This is said to imply a libration of the equinoxes, and this notion of libration or a modification of it appears to have been the theory generally accepted by the Hindus.

The modern *Sūrya Siddhānta* (iii. 11-12) says: "The circle has moved eastward, when the longitude of the sun, as obtained by calculation, is less than that derived from the shadow, by the number of degrees of the difference; then, turning back it has moved westward by the amount of the difference when the calculated longitude is greater."

As Whitney points out, it is evident that the initial point of the sphere was regarded as the movable point and the equinox as the fixed one. This very curious idea was not peculiar to the Hindus, for Albīrūnī condemns Varāha Mihira because he "had no knowledge of the motion of the fixed stars towards the east" "The solstice has kept its place," he says, "but the constellations have migrated, just the very opposite of what Varāha Mihira has fancied." The supposed motion of the constellation Ursa Major, already referred to, is no doubt connected with the same idea.

The rule for calculating the amount of precession is this: (a) "In an age (i.e., 4,320,000 years) the circle of the asterisms nakshatra falls back eastwards six hundred revolutions. (b) Of the result obtained after multiplying the sum of days by this number, and dividing by the number of natural days in an age, (c) take the part which determines the sine, multiply it by three, and divide by ten: thus are determined the degrees of precession."

There are here three separate directions: (a) gives the period of revolution as $\frac{4,320,000}{600} = 7,200$ years; (b) directs us to find the fraction of a revolution (the phase) at the given time and (c) states how the actual precession is calculated.

The revolutions referred to are those of a point on an epicycle whose centre is at a fixed point on the ecliptic as deferent, and the radius of the epicycle is $\frac{3}{10}$ of the radius of the deferent.

The angle subtended by the radius of the epicycle at the centre of the deferent is therefore approximately $17\frac{1}{2}$ degrees. In one revolution of the epicycle the precession is $4 \times 17\frac{1}{2}^{\circ}$ and as one revolution takes place in 7,200 years the amount of precession a year is approximately 35 seconds.² Other texts

¹ P.S. iii. 20. The scheme is the improved parallel scheme (*Anticis* of Firmicus, after Dorothea of Sidon). Bouché Leclercq, p. 161. See also Albīrūnī, ii, p. 204.

(1) *JAS* 1858, p. 244. (2) *India* ii, 88. (3) *SS*, iii, 9-10. (4) Whitney gives 600 but points out that Bhāskara gives 30. The phrase in question possibly means 'thirty squared,' which would give an annual precession of 52.5."

² Ptolemy's value was 36 seconds.

appear to give 27 as the radius of the epicycle.¹ Bhāskara discards the libration theory and gives a complete revolution in about 21,636 years or a yearly rate of practically one minute of arc; but Bhāskara's teaching on this point was not accepted by the Hindu astronomers and the libration theory seems generally to have prevailed.²

HINDU STAR LISTS.

63. The determination of the position of the stars with exactitude does not seem to have interested the ancient Hindu astronomers.³ In early works the brief lists of stars with celestial co-ordinates given are generally in connexion with the path of the sun and moon through the nakshatras. In each nakshatra the position of a junction star or *yogatārā* was determined. The *Pañchasiddhāntikā* mentions seven of these while the *Sūrya Siddhānta* gives the position of 28, one for each nakshatra, and also of seven other stars.

The *Pañchasiddhāntikā* record is as follows:—

“The *yogatārā* of KRITIKĀ is at the end of the sixth degree and three and a half *hastas* to the north of the ecliptic; that of ROHIṆĪ is at the end of the eighth degree, and five and a half *hastas* to the south of the ecliptic.” (XIV, 34) “The two stars of PUNARVASU are at the eighth degree, and to the north and south of the ecliptic at an interval of eight *hastas*. The star of PUSHYA is at the fourth degree, three and a half *hastas* to the north.” “Of ĀŚLESHĀ the southern star is at the first degree one *hasta* (south); so also the northern star of MAGHĀ, the conjunction takes place in its own field,⁴ at the sixth degree. Of CHITRĀ at seven and a half degrees, three *hastas* to the south.”⁵

¹ According to Theon some ancient astrologers had found that the stars had an oscillation of 8 degrees back wards and forwards in 672 years. (DELABRE, ii, 625) Abū'l Hasan assumed that the motion took place in a circle, whose radius occupied 10 degrees of the ecliptic and whose centre was absolutely fixed. The rate of motion was supposed to be $90^{\circ} 9'$ in 1,000 years, which corresponds to an average of $36''$ a year in the ecliptic itself. Regiomontanus gave the circle a radius of $4^{\circ} 18'$. Copernicus examined the theory of trepidation and pointed out that the records appeared to indicate a persistent variation in the motion; and it was not until the sixteenth century that its regularity was re-established. “The authority of Tycho Brahe was so great that the mere fact of his having ignored the phenomenon of trepidation was sufficient to lay this spectre which had haunted the precincts of Urania for a thousand years and possibly much longer.” DREYER, *Tycho Brahe*, p. 356.

² Albirūnī (*India* i, 366) thought that the Hindus discovered that the real solstice preceded the solstice of their calculation in A.D. 989; and he points out that “Puṣjala, the author of the *Small Mānasa*, says that in the year 854 of the *Sakābāla* the real solstice preceded his calculation by $6^{\circ} 50'$, and that this difference will increase in future by one minute every year.” See also COLEBROOKE *Essays* ii, 332, 333.

³ Alberūnī writes (II, 83): “The Hindus are very little informed regarding the fixed stars. I never came across any one of them who knew the single stars of the lunar stations from eyesight, and was able to point them out to me with his fingers.”

⁴ i.e., on the ecliptic.

⁵ Since 24 *aṅgulas* = 1 *hasta* and the diameter of the moon was reckoned as 15 *aṅgulas*, and its mean diameter as 32 minutes (SS. IV, 1) we have approximately 1 *aṅgula* = $2^{\circ} 8'$ and 1 *hasta* = $51^{\circ} 12'$ roughly; but possibly 1 *aṅgula* was meant to measure 2 minutes. Also 27 *nakshatras* occupy 360° and one therefore occupies $13\frac{1}{3}$ degrees.

The *Sūrya Siddhānta* gives the positions of the chief stars of the nakshatras in terms of polar latitude and longitude.¹ The *Sūrya Siddhānta* stars are given in appendix iii, table 1.

HINDU ASTRONOMICAL INSTRUMENTS.

64. The only instruments of practical utility for astronomical purposes described in ancient Hindu works are the sun-dial and clepsydra. An armillary sphere is also described as an instrument for purposes of demonstration. The only Hindu instrument of any antiquity actually found is the clepsydra, consisting of a metal bowl floating in a vessel of water.²

The following is a summary of those parts of the early Hindu texts that deal with astronomical instruments. (i) The CLEPSYDRA or Water clock is referred to in the *Jyotisha Vedāṅga*, where the amount of water that measures a *nāḍikā* (=24 minutes) is given. The more ancient form of water clock appears to have been simply a vessel with a small orifice at the bottom, through which the water flowed out in a *nāḍikā*³, but later on there came into use the form described in the *Sūrya Siddhānta* (XIII, 23): "A copper vessel, with a hole in the bottom, set in a vessel of pure water, sinks sixty times in a day and night, and is an accurate hemispherical instrument." The *Pañchasiddhāntikā* description⁴ (XIV, 32) is similar, but adds "Or else a *nāḍikā* may be measured by the time in which sixty slokas, each consisting of sixty long syllables, can be read out."

A later description of the clepsydra is as follows: "A copper vessel, weighing 10 *palas*, six *aṅgulas* in height and twice as much in breadth at the mouth—this vessel of the capacity of 60 *palas* of water, and hemispherical in form, is called a *ghaṭi*. The aforesaid copper vessel, bored with a needle made of $3\frac{1}{2}$ *māśhas*⁵ of gold and 4 *aṅgulas* long, gets filled in one *nāḍikā*."

In practice, no doubt, the dimensions of the bowl and the orifice were determined by experiment. Bhāskara (XI, 8) indeed says: "See how often it is filled and falls to the bottom of the pail of water in which it is placed. Divide 60 *ghaṭis* of day and night by the quotient, and it will give the measure of the clepsydra."

(ii) THE GNOMON.—The sun-dial described in the early treatises is of the simplest kind, consisting of a vertical rod, or gnomon, divided into 12 divisions. The descriptions are of a theoretical nature, and do not apply so much to the construction of instruments as to theoretical calculations. The *Pañchasiddhāntikā* (XIV, 14-16) instructions are: "Mark from the centre three times the end of the gnomon's shadow, and then describe two fish figures. Thereupon describe a circle, taking for radius a string that is fastened to the point in

¹ See page 53.

² It is the only instrument described in the *Āin-i-Akbari* (Ed. Jarret III, 16).

³ J. F. Fleet *The Ancient Indian Water Clock* J.R.A.S., 1915, pp. 213-230.

⁴ Lala Chhottee Lal's *Jyotisha Vedāṅga*, p. 12.

⁵ About 56 grains troy. Fleet quotes another rule, which gives the weight as a *survarṇa* (=16 *māśhas*), and length 4 *aṅgulas*, drawn out round or square. Bhāskara simply says (XI, 8) it "should have a hole bored in its bottom."

which the two strings issuing from the heads of the fish figure¹ intersect, and that is so long as to reach the three points marked. On the given day the shadow of the gnomon moves in that circle, and the base of the gnomon is the south-north line; and the interval, in the north direction, is the midday shadow." (III, 1-7) This means, mark on any particular day the extremity of the shadow at three different times—and these three points are supposed to lie on a circle, the centre of which is found (in the usual way) by the so-called fish figures.¹

The *Sūrya Siddhānta* directions (III, 1-7) are more elaborate but relate to exactly the same type of dial. They are as follows:—

"On a stony surface, made water level, or upon hard plaster, made level, there draw an even circle of a radius equal to any required number of digits of the gnomon. At its centre set up the gnomon of twelve digits of the measure fixed upon; and, where the extremity of its shadow touches the circle in the former and after parts of the day, there, fixing two points upon the circle, and calling them the forenoon and afternoon points, draw midway between them, by means of a fish figure, a north and south line. Midway between the north and south directions draw, by a fish figure, an east and west line: and, in like manner, also by the fish figures, between the four cardinal directions, draw the intermediate directions. Draw a circumscribing square, by means of the lines going out from the centre: by the digits of its base lines projected upon that, is any given shadow reckoned. The east and west line is called the prime vertical (*śama-maṇḍala*): it is likewise denominated the east and west hour circle (*unmaṇḍala*), and the equinoctial circle (*vishuvan maṇḍala*). Draw likewise an east and west line through the equinoctial shadow (*vishuvad-bhā*); the interval between any given shadow and the line of the equinoctial shadow is denominated the measures of the amplitude (*agrā*)."

(iii) ARMILLARY SPHERE.—The *Sūrya Siddhānta* (XIII, 1-16) gives instructions for the making of an elaborate armillary sphere:—

"Let the teacher, for the instruction of the pupil prepare the wonder working fabric of the terrestrial and stellar sphere (*bhūbha gola*). Having fashioned an earth-globe of wood, of the desired size, fix a staff, passing through the midst of it and protruding at either side for Meru; and likewise a couple of sustaining bands and the equinoctial circle; these are to be made with graduated divisions of degrees of the circle. Further, by means of the several day-radii, as adapted to the scale established for those other circles, and, by means of the degrees of declination and latitude marked off upon the latter, at their own respective distances in

¹ The 'fish figure' is the common part of two intersecting circles.

declination, according to the declination of Aries, etc., three bands are to be prepared and fastened: these answer also inversely for Cancer, etc. In the same manner, three for Libra, etc., answering also inversely for Capricorn, etc.: and, situated in the southern hemisphere, are to be made and fastened to the two band-supporters. Those, likewise, of the asterisms situated in the southern and northern hemispheres, of Abhijit, of the Seven Sages (*Saptarshayas*) of Agastya, of Brahma, etc., are to be fixed. Just in the midst of all the equinoctial band is fixed. Above the points of intersection of that and the supporting bands are the two solstices (*ayana*) and the two equinoxes (*vishuvat*). From the place of the equinox, with the exact number of degrees, as proportioned to the whole circle, fix by oblique chords, the spaces of Aries and the rest; and so, likewise, another band, running obliquely from solstice to solstice, and called the circle of declination (*krānti*): upon that the sun constantly revolves giving light: the moon and the other planets, also by their own nodes, which are situated in the ecliptic (*apa maṇḍala*), being drawn away from it, are beheld at the limit of their removal in latitude (*vikshepa*) from the corresponding point of declination. The orient ecliptic point (*lagna*) is that of the orient horizon; the occident point (*astamgachhat*) is similarly determined. The meridian ecliptic point (*madhyama*) is as calculated by the equivalents in right ascension (*lankodayās*), for mid heaven (*hamadhya*) above. The sine which is between the meridian and the horizon (*kshitiṇa*) is styled the day measure (*antyā*), and the sine of the sun's ascensional distance (*chakradala*) is to be recognised as the interval between the equator and the horizon. Having turned upward one's own place, the circle of the horizon is midway of the sphere. As covered with a casing (*vastra*) and as left uncovered, it is the sphere surrounded by Lokāloka. By the application of water is made ascertainment of the revolution of time. One may construct a sphere instrument combined with quicksilver; this is a mystery, if plainly described it would be generally intelligible to the world. Therefore let the supreme sphere be constructed according to the instruction of the preceptor. In each successive age, this construction having become lost, is by the sun's favour again revealed to some one or other at his pleasure."

- (iv) OTHER INSTRUMENTS.—"So also," the text continues, "one should construct instruments (*yantras*) for the ascertainment of time. When quite alone, one should apply quicksilver to the wonder causing instrument.¹ By the gnomon (*śanku*), staff (*yashti*) arc (*dhanus*), circle (*chakra*), instruments for taking the shadow of

¹ See the *Siddhānta Śiromaṇi* xi 50-51. The instrument appears to be a perpetual motion machine, which consists of a wheel with hollow (? tangential) spokes, which are filled with mercury. "The wheel thus filled will, when placed on an axis supported by two posts, revolve of itself."

various kinds By water instruments, the hemisphere (*kapāla*), etc., by the peacock, man, monkey, and by stringed sand receptacles, one may determine time accurately. Quicksilver-holes, water, and cords, ropes and oil and water, mercury, and sand are used in these: these applications, too, are difficult So also a dial (*narayontra*) is good in daytime, and when the sun is clear."

Such is the orthodox Hindu text relating to instruments. Nothing of material value appears to have been added to these instructions until the methods of the *Yavanas* were introduced, by Mahendra Sūri and others; but Bhāskara claims to have invented an instrument called PHALAKA YANTRA,¹ which, he says, is an "excellent instrument, calculated to remove always the darkness of ignorance and is the delight of clever astronomers." This instrument is simply a board divided by horizontals into 90 equal parts. At the centre of the 30th graduation from the top, a pin, or style, is placed perpendicular to the board, and round it a circle is drawn of radius=30 divisions, which is graduated in ghaṭis and degrees, and attached to the pin is an index arm (*paṭṭika*). The instrument is suspended by a chain, and is used for observational purposes. It is in fact part of a very simple astrolabe. Bhāskara did not seem very pleased with his instrument, for, he concludes (XI, 40) by saying "But what does a man of genius want with instruments, about which numerous works have treated? Let him only take a staff in his hand, and look at any object along it, casting his eye from its end to the top. There is nothing of which he will not then tell: its altitude, dimensions, etc."

¹ Compare the 'Balance Étorarie ou Fézairé' described by DELAMBRE *Astronomie du Moyen Âge*, p. 521.

CHAPTER IX.

Mathematical astronomy.¹

65. The following notes are the result of an attempt to summarise, with the aid of modern mathematical formulæ, the more technical portions of the classical Sanskrit astronomical texts.

The texts dealt with are the *Āryabhaṭīya* (A.D. 498), the *Pañchasiddhāntikā* (circa A.D. 550), the *Brāhmasphuṭasiddhānta* (A.D. 628), and the later *Sūrya Siddhānta* (circa A.D. 1000). The period covered, it will be noticed, corresponds pretty closely with the period that was characterised by a remarkable renaissance of literature, art and science in India; and the following paragraphs indicate in a somewhat forcible manner, but, of course, only in part, the scope of intellectual activity in India in that early time. This summary may indeed, be looked upon as an aid to the study of a particular intellectual phase of that period; and this ancillary function has partly determined the form of presentation of the material.

SPHERICAL TRIGONOMETRY.

Although no formal spherical trigonometry is exhibited in any text, the early Hindu astronomers were obviously acquainted with principles that enabled them to solve spherical triangles. This statement, however, requires some qualification. The Hindu school of mathematicians preferred to deal in lengths rather than angles; they had no geometry of angles; and their rules are in all cases stated as results without reference to the methods by which they were obtained, and these methods are consequently buried in obscurity. As these ancient astronomers were chiefly interested in results it is possible, if we assume that they obtained these results from outside sources and were not interested in the mathematical principles involved, to conceive that they were not acquainted with those principles; but the assumption is rather a strain, as there are too many formulæ based upon the spherical triangle to be explained away. We may therefore certainly say that traces of the principal formulæ of spherical trigonometry are found in the Hindu texts.² On the other hand there occur indications which point to some lack of a knowledge of the mathematical principles involved, and we may certainly say that these principles were treated with a certain amount of indifference. In several of the astronomical rules summarised below there are then at least traces of the following rules of spherical trigonometry:—

$$(i) \quad \cos c = \cos a \cos b + \sin a \sin b \cos C$$

$$(ii) \quad \sin A \sin c = \sin a \sin C$$

$$(iii) \quad \cos A \sin c = \cos a \cos b - \sin a \cos b \cos C$$

where A, B, C are the angles of a spherical triangle, and a, b, c are the corresponding opposite sides.

¹ This chapter first appeared in the *Journal of the Asiatic Society of Bengal*, 1919.
See also A. v. BRAUNMÜHL *Vorlesungen über Geschichte der Trigonometrie*, p. 41.

The Indian astronomers employed the sine function principally, and the versed sine ($= 1 - \cos a$) occasionally; they never employed the tangent function; and generally, but not always, preferred to employ the sine of the complementary angle rather than the cosine function.

In translating the Hindu rules into modern notation it must be borne in mind that the Hindu sine function is a length, not a ratio; and denoting the Pauliśa sine by $\sin P$, the Āryabhaṭa sine by $\sin A$, the Brahmagupta sine by $\sin B$ and the modern sine by $\sin a$, where the arcs P , A , B and a are the same, we have

$$\frac{\sin P}{p} = \frac{\sin A}{a} = \frac{\sin B}{b} = \sin a$$

a , p and b being the Āryabhaṭa, Pauliśa and Brahmagupta radii, measured in different units. When actual values for the sines are given, which is very seldom in the texts,¹ we have

$$\frac{\sin P}{120} = \frac{\sin A}{3438} = \frac{\sin B}{3270} = \sin a.$$

66. It should also be borne in mind that the rules are always expressed fully in words, and that the more complicated formulæ are built up in stages. Here is a fairly typical example² in which the stages are marked A, B, C, etc.

“(A) If the radius be multiplied by a given shadow and divided by the corresponding hypotenuse, the result is the sine of the zenith distance. (B) The square-root of the difference of the square of that and the square of the radius is the sine of the altitude, (C) which multiplied by the radius and divided by the sine of the co-latitude gives the divisor.’ (D) Multiply the latter by the radius and divide by the radius of the diurnal circle and the quotient is the sine of the *unnata*: (E) this, then, being subtracted from the day measure and the remainder turned into arc by means of the tables of versed sines, the final result is the hour angle.”

The operations indicated are:

(A) $\sin z = rs/H$, (B) $\sin (90^\circ - z) = \sqrt{r^2 - A^2}$,
 (C) $rB / \sin (90^\circ - \varphi)$, (D) $rC - r \cos \delta$, where $r \cos \delta$ is the
 ‘radius of the diurnal circle,’ (E) $r + r \tan \varphi \tan \delta - D$, where $r + r \tan \varphi \tan \delta$ is the ‘day measure.’

This means

$$\begin{aligned} \text{versin } h &= r + r \tan \varphi \tan \delta - C / \cos \delta \\ &= r + r \tan \varphi \tan \delta - rB / \cos \delta \cos \varphi \\ &= r + r \tan \varphi \tan \delta - r \cos z / \cos \delta \cos \varphi \end{aligned}$$

or $\cos h = \cos z / \cos \delta \cos \varphi - \tan \varphi \tan \delta$
 when $r = 1$.

¹ The *Pauliśa Siddhānta* (PS.—iv, 24) gives $\sin 24^\circ = 48' 48''$, while the *Sūrya Siddhānta* (ii, 28) gives $\sin 24^\circ = 1397'$, the modern value being 0.4067 approximately. Now $4067 \times 120 = 48804$ and $4067 \times 3438 = 139820$. See also § 54.

² From the *Sūrya Siddhānta*—iii, 37-39. See paragraph 68(b) iv, below.

DEFINITIONS.

67. (a) In figure 1 the horizon (*kshitiya*) is represented by NES , the equator (*vishuvadvritta*) by EQ , the pole is P , the zenith (*dris*) is Z , and FGR is the diurnal path of a star. The angle $PON = ZOQ = \varphi$ is the terrestrial latitude (*aksha*) of the place O , the angle $ROQ = \delta$ is the declination (*krānti*) of the star and the angle $EOF = a_0$ is its

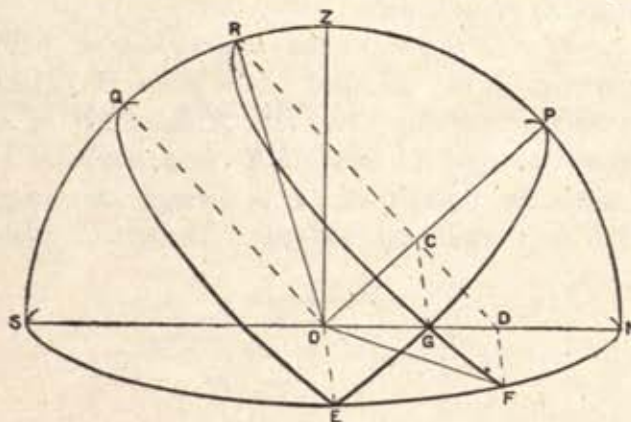


Fig. 1.

amplitude when on the horizon. The circle PGE , passing through the pole and the east and west points, is the so-called 'six-hour circle' (*unmaṇḍala*).

Denoting the radius QO by r we have

- (i) $RC = r \cos \delta$, the 'day radius' (*dinavyāsadala*)
- (ii) $CD = r \sin \delta \tan \varphi$, the 'earth sine' (*kshitiḥyā*)
- (iii) $\sin a_0 = OD/OF = \sin \delta / \cos \varphi$
- (iv) $RD = r \cos \delta + r \sin \delta \tan \varphi = r \cos \delta (1 + \tan \varphi \tan \delta)$ where $(1 + \tan \varphi \tan \delta)$ is termed the 'day measure' (*antyā*)

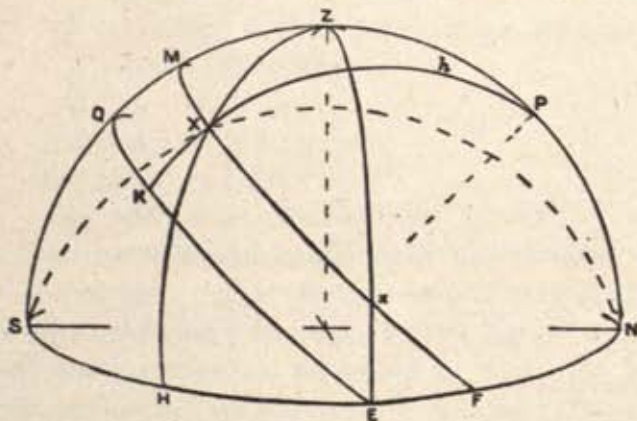


Fig. 2.

- (v) $\sin GCF = CD/CF = CD/RC = r \sin \delta \tan \varphi / r \cos \delta = \tan \varphi \tan \delta$, and $GCF = \Delta a$ is termed the 'ascensional difference' (*chāra*).¹

¹ At sun-rise the hour angle $RCF = 90^\circ + \Delta a$, consequently $\cos h = -\sin \Delta a = -\tan \varphi \tan \delta$

(b) In figure 2, NES is the horizon, $NZMS$ is the meridian (*yāmyottaravṛtta*), QKE is the equator, ZE is the prime vertical (*samamaṇḍala*); X is the position of a star, and MXF is its diurnal path. The angle $ZPX = h$ is the hour angle (*nata*), the arc $NSH = a$ is the azimuth, ZXP is the parallactic angle, NXS is the so-called 'circle of position,' and $NXP = \xi$ is the *aksha valana*, or 'deflection due to latitude.'

(c) In figure 3, $Q \tau R$ represents the equator and $C \tau L$ the ecliptic (*apa-maṇḍala*). The point τ is the so-called 'first point of Aries.' The sun moves along the ecliptic in the direction τdL . The circle PXP' is a declination circle (*krāntivṛtta*) through the star X , and KXK' is a circle of latitude (*vikshepa*). In some Hindu texts τa instead of τd is termed the longitude of X , and Xa instead of Xd is termed the latitude. These are sometimes called the

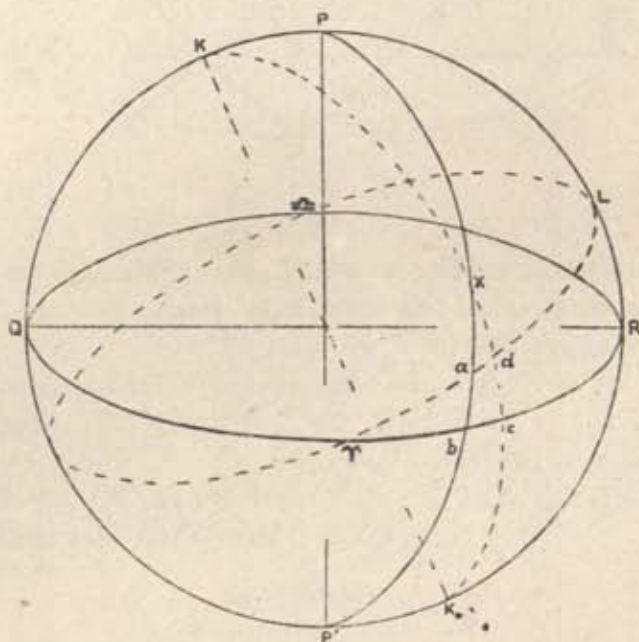


Fig. 3.

'polar' or 'false' longitude and latitude. The obliquity $\omega = L \tau R$ is only indicated as the maximum declination of the sun, or LR , and is generally assumed to be 24 degrees. Denoting the true longitude τd by λ and the false longitude τa by λ' , and similarly the true (dx) and false (ax) latitudes by β and β' , and the angle τab by A , and noting that the angle of $a \tau b = \omega$, and $\tau ba = 90^\circ$ and also $\tau dc = 90^\circ$, we obtain from the spherical triangles τab and xda

$$(i) \tan A = \cot \omega / \cos \lambda', \quad (ii) \sin A = \sin \beta / \sin \beta'.$$

$$(iii) \sin \lambda - \lambda' = \tan \beta / \tan A.$$

(d) In figure 4, $OA = g$ represents a vertical gnomon (*śanku*), NOS and EOW are the north and south and east and west lines through the base of the gnomon. If $OF = e$ is the equinoctial noon-day shadow (*vishuvadhā*) for

northern latitude φ , then FG , parallel to OW , is the locus of the equinoctial shadow, and the line $BO = s$ represents the shadow at a time when the sun's declination is south. Draw BH parallel to NS and denote BG by A ; then $BH = A + e$. The line $BH = s \sin \theta$ is termed the *bhuja*, $BC = s \cos \theta$ the *koti*, and BG or $A = s \sin \theta - e$ is termed the *agrā*.¹ The angle $FAO = \varphi$, and $BAO = z$.

RULES AND PROBLEMS.

68. In this section we summarise the principal rules given in the *siddhāntas*.

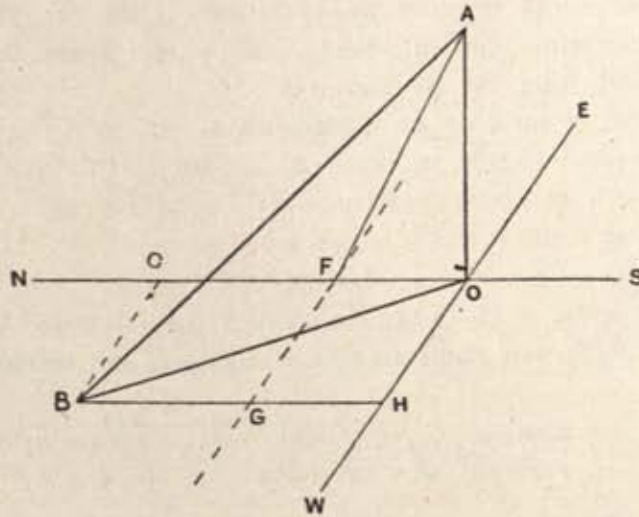


Fig. 4.

(a) *The gnomon*.—From figure 4 the following are obtained:—

- (i) Angle $CAO = z_n + \varphi - \delta$
- (ii) „ $FAO = \varphi$
- (iii) $\tan \varphi = OF/OA = e/g$
- (iv) $\sin z = BO/BA = s/H$
- (v) $\cos z = AO/BA = g/H$.

(b) *The hour angle, azimuth and zenith distance*.—In the triangle XPZ in figure 2 we have $ZP = 90^\circ - \varphi$, $XP = 90^\circ - \delta$, $ZX = z$, $ZPX = h$ and $XZP = 360^\circ - a$. From formulæ i-iii in paragraph 65 we obtain

- (i) $\cos z = \sin \varphi \sin \delta + \cos \varphi \cos \delta \cos h$
- (ii) $\sin a \sin z = -\cos \delta \sin h$
- (iii) $\cos a \sin z = \cos \varphi \sin \delta - \sin \varphi \cos \delta \cos h$

and from these we get

- (iv) $\cos h = \cos z / \cos \varphi \cos \delta - \tan \varphi \tan \delta$
 $= (g/H \cos \varphi - \sin \delta \sin \varphi / \cos \varphi) / \cos \delta$
- (v) $\cos a = \sin \delta / \sin z \cos \varphi - \tan \varphi / \tan z$.

¹ $A = \pm (s \sin \theta - e)$ when B is north of EW (the positive sign to be taken when it is north of FG).

At the moment of rising since $z = 90^\circ$, we have from (iv)

$$(vi) \cos h = -\tan \varphi \tan \delta$$

or, if $h = 90^\circ + \Delta \alpha$ we get

$$(vii)^1 \sin \Delta \alpha = \tan \varphi \tan \delta$$

where $\Delta \alpha$ is called the ascensional difference (*chara* or 'variable').

(c) *Declination and longitude*.—In figure 3, if a is the position of a star on the ecliptic then Υa is its longitude λ , its declination $\delta = ab$, and its maximum declination $\omega = LR$ or $L^\perp R$. Solving the right-angled triangle Υab we have

$$\begin{aligned} \sin \delta &= \sin a \Upsilon b \sin a \Upsilon \\ &= \sin \omega \sin \lambda \end{aligned}$$

(d) *To find the zenith distance when the star is on the prime vertical*.—If the star is on the prime vertical, that is at x in figure 2, then $a = 270^\circ$ and $\cos a = 0$ and from (b) (i) and (iii)

$$\cos z = \sin \delta / \sin \varphi = \sin \lambda \sin \omega / \sin \varphi.$$

(e) *The koṇasaṅku*.²—Again in figure 2, if $SH = 45^\circ$ then $a = 180^\circ + 45^\circ$ and $\cos a = -1/\sqrt{2}$, and from the triangle XPZ or b (v) we get

$$\begin{aligned} \sin \delta &= \cos z \sin \varphi + \sin z \cos \varphi \cos a \\ &= \cos z \sin \varphi - \sin z \cos \varphi / \sqrt{2} \end{aligned}$$

$$\text{or } \cos^2 z (2 \tan^2 \varphi + 1) - 4 \tan \varphi \cos z \sin \delta / \cos \varphi + 2 \sin^2 \delta / \cos^2 \varphi = 1.0.$$

Substituting in this e/g for $\tan \varphi$ and $\sin a_0$ for $\sin \delta / \cos \varphi$, and solving for $\cos z$, we get

$$\cos z = \frac{ge \sin a}{e^2 + g^2/2} \pm \sqrt{\frac{g^2 (\frac{1}{2} - \sin^2 a_0)}{e^2 + g^2/2} + \frac{(ge \sin a_0)^2}{(e^2 + g^2/2)^2}}$$

(f) *The agrā*.—Substituting $\sin a_0$ for $\sin \delta / \cos \varphi$, s/H for $\sin z$, and g/H for $\cos z$ in (b) (v), we get

$$(i) s \cos a + e = H \sin a_0.$$

For the point B in figure 4 we have φ and z both positive, δ negative (which makes $\sin a_0$ negative), $a = 90^\circ + BOH$ and $\cos a = -\sin BOH$. Consequently (i) becomes $s \sin BOH - e = H \sin a_0$. But $\sin BOH = (BG + GH)/BO = (A + e)/s$ and $s \sin BOH - e = A$. Consequently

$$(ii) A = H \sin a_0 = H \sin \delta / \cos \varphi,$$

where A is the *garā*—which may be defined as the perpendicular from the extremity of the shadow to the equinoctial line.

(g) *The drikshēpa*.—The central ecliptic point, or point on the ecliptic that is 90 degrees from the horizon is termed the *nonagesimal point* or *tribhona-lagna* or *vitribha*, and the sine of its zenith distance (z_0) is termed *drikshēpa*, and its cosine *driggati*. The rule for the *drikshēpa* or $\sin z_0$ is evolved thus: In figure 5 where $N \Upsilon H$ is the ecliptic, ΥE the equator, EHS the horizon, ZMS the meridian and N the nonagesimal, we have $H \Upsilon N = 90$ degrees, $H \Upsilon E = \omega$ and $\Upsilon EH = 90^\circ - \varphi$. From the triangle HE we obtain $\sin HE \sin \Upsilon EH = \sin \Upsilon H \sin H \Upsilon E$, or

¹ Of these only (iv) and (vii) appear explicitly in the texts.

² *Ārya Śiddhanta* iii, 24.

correctly imply that it is the angle $NXK = \xi - x$, that is, the angle between the circle of position and the circle of latitude, or, what is the same thing, the angle CXE' between a circle (XE') parallel to the prime vertical and the ecliptic.

In the triangle PXK since $KXP = x$, $PK = \omega$, $KX = 90^\circ$ and $XP = 90^\circ - \delta$, we have

$$\begin{aligned} \text{(i) } \sin x &= \sin PX \sin XKP / \sin XP \\ &= \sin \omega \sin (90^\circ + \lambda) / \cos \delta \end{aligned}$$

and in the triangle NXP

$$\text{(ii) } \sin \xi = \sin PN \sin \varphi / \cos \delta,$$

for which the text substitutes $\sin h \sin \varphi / \cos \delta$. The angle $NXP = \xi$ is termed *aksha valana*, or 'deflection due to latitude,' and the angle x is termed *āyana valana*, or 'deflection due to obliquity.'

(i) *The drikarma and planetary conjunctions.* By some of the later Hindu astronomers the subject of planetary conjunctions is considered. Two planets are said to be in conjunction when they are on the same circle of position (that is on the same secondary to the prime vertical), and on such a circle the

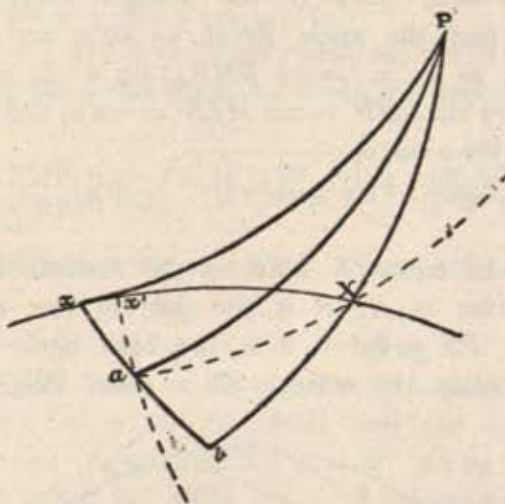


Fig. 7

stars rise and set simultaneously. Unless, however, the circle of position coincide with a circle of latitude, the two stars cannot have the same true longitude, and it becomes necessary to find the longitude of the point of intersection of the circle of position with the ecliptic, when the true longitude of the star is known.

In figure 7, $x'a$ is a portion of the ecliptic, and aX and $x'X$ are respectively the circle of latitude and the circle of position through the heavenly body at X . The problem is to find the longitude of x' when that of a is known.

Let xab be the day circle of the point a and x the point of intersection between this day circle and the circle of position, then the first step in the solution of the problem is to assume that ax is sufficiently nearly equal to $x'a$ for the purpose in hand.

Draw the declination circles Px , Pa , Pb through the points x , a , and X , the last cutting the day circle in b , and denote the angles aPb and xPb by ψ_1 and ψ_2 .

We have $xa = xb - ab$, and it may be noted that at the solstices aX and aP coincide and ab disappears. The process of determining ab is therefore called *āyanadrīkarma*; while at the equator aX and Pb would coincide and then xb would disappear and the process of determining xb is termed *akshadrīkarma*.

(i) *Āyanadrīkarma*.—The angle PaX between the circle of declination Pa and the circle of latitude aX is the *ayanavalana* (see (h)) and we have

$$\begin{aligned}\sin \psi_1 &= \sin aX \sin PaX / \sin PX \\ &= \sin \beta \sin \alpha / \cos \delta.\end{aligned}$$

(ii) *Akshadrīkarma*.—The angle PxX is nearly equal to the *akshavalana*, ξ , and $\sin xX = \sin bX / \sin Xxb$ and $bX = \beta'$, the polar latitude, so we have

$$\begin{aligned}\sin \psi_2 &= \sin xX \sin PxX / \sin PX \\ &= \sin \beta' \sin \xi / \cos \delta \sin Xxb \text{ nearly,}\end{aligned}$$

and at the horizon the angle Xxb is equal to the colatitude of the place.

THE ASCENSIONAL DIFFERENCE.

69. At the equator, where the horizon is at right angles to the equator, the apparent daily paths of the stars are circles at right angles to the horizon, and we have *right ascensions*; while at the poles the apparent daily paths are parallel to the horizon; but at any other latitude (ϕ) they are inclined to the horizon and we have *oblique ascensions*. The Greek astronomers paid considerable attention to the relation between right and oblique ascensions and determined therefrom correct rules for the calculation of the length of the day, rules and tables connected with the rising sign or ascendant or horoscope, culminating signs, and problems in which the sun's declination and terrestrial latitude were involved.

In figures 8 and 9 the horizon is represented by AC , the ecliptic by Cr and the equator by $A\tau$. The arc $A\tau$ is termed the *ascensional equivalent* of rC , the arc τA being that portion of the equator and τC that portion of the ecliptic that rise in the same period. At the equator CB coincides

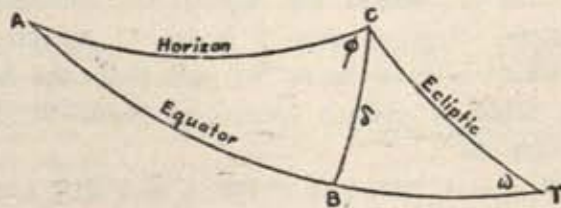


Fig. 8.

with CA and $rA = rB$ is the equivalent of rC in right ascension, or the right co-ascendant; for the latitude φ the equivalent in oblique ascension (or oblique co-ascendant) is rA , and AB is the *ascensional difference*.

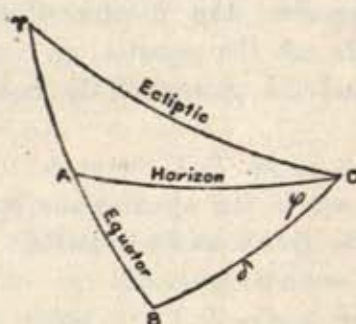


Fig. 9.

In the triangles $rABC$ we have $rC = \lambda$ or $360^\circ - \lambda$, $CB = \delta$, the angle $A rC = \omega$, and the angle $ACB = \varphi$; and consequently

$$(i) \sin rB = \sin a, = \sin \lambda \cos \omega / \cos \delta$$

$$(ii) \sin AB = \sin \Delta a = \tan \varphi \tan \delta$$

$$(iii) rA = a_0 = a, \mp \Delta a$$

where a , denotes right ascension, a_0 oblique ascension, and Δa ascensional difference.

To calculate the time of rising of any particular sign we have

$$(iv) t_n = a_{r(n)} - (\Delta a_n - \Delta a_{n-1})$$

where t_n is expressed in degrees, and n refers to the n^{th} sign according to the order given in tables 9 and 10.

The *Paulīsa Siddhānta* gives the ascensional differences in the form $20e$, $16\frac{1}{2}e$, $6e$ where e is the equinoctial noonday shadow. Brahmagupta similarly gives $19e$, $16\frac{1}{4}e$, $6e$. The only table of oblique ascensions appears to be the very rough one in Varāha Mihira's *Bṛīhaj Jātaka*; the later *Sūrya Siddhānta* gives right ascensions, but none of the early Hindu texts appears to give correct tables for oblique ascensions or ascensional differences. The fairly accurate tables given in tables 9 and 10 are taken from Abū 'Alī al-Marrākoshī (13th century).

70. THE LAGNA.—The point of the ecliptic on the horizon (horoscope, ascendens) at any time is termed the *lagna*. Its determination may be explained by an example. Suppose that 7 hours 17 minutes has elapsed since sunrise at a place whose latitude is 36°N. , and that the longitude of the sun is 42 degrees. The table of oblique ascensions (table 9), converted into time units, gives for latitude 36°

$$t_1 = 1^{\text{h}} 17^{\text{m}}, t_2 = 1^{\text{h}} 31^{\text{m}}, t_3 = 1^{\text{h}} 57^{\text{m}}, t_4 = 2^{\text{h}} 21^{\text{m}}, t_5 = 2^{\text{h}} 28^{\text{m}}.$$

Since the sun has advanced 12 degrees into the second sign we have first to find how much of t has not been used up. This is $(1^{\text{h}} 31^{\text{m}}) \times (30^\circ - 12^\circ)/30^\circ = 55$ minutes approximately.

Now

$$7^h 17^m = 55^m + 1^h 57^m + 2^h 21^m + (2^h 4^m).$$

the last term being less than t_2 . The time then corresponds to some point in t_2 (Leo); and since

$$x/30 = (2^h 4^m)/(2^h 28^m)$$

gives $x = 25^\circ 8'$ the longitude of the *lagna* is approximately 4 signs 25 degrees 8 minutes.¹

71. LENGTH OF DAY.—The difference between the length of the day and night is equivalent to four times the angle GCF in figure 1, when FGR represents the path of the sun. Now $\sin GCF$ or $\sin \Delta a$ has been shown (§ 5(a) v) to be equal to $\tan \varphi \tan \delta$. The length of the day in hours is therefore $(180^\circ + 2 \Delta a)/15$ and in ghaṭis it is $(180^\circ + 2 \Delta a)/6$ where $\sin \Delta a = \tan \varphi \tan \delta$, and for the longest day $\sin \Delta a = \tan \varphi \tan \omega$.† This rule is given by Pauliṣa (*P.S.* iii, 11) and Brahmagupta, and Āryabhaṭa (*G* 19) notes the connexion with the 'six hour circle'.³

No tables of the lengths of days are given in the early Hindu texts: the following is taken from Abū 'Alī al-Marrākoshī.

Longest days for different latitudes.

Latitude.	3°	6°	9°	12°	15°	18°	21°	24°	27°	30°	33°	36°	39°	42°	45°	48°	51°	54°	57°	60°	63°	66°
Hours	12	12	12	12	12	13	13	13	13	13	14	14	14	15	15	15	16	16	17	18	19	22
Minutes	10	21	31	42	53	5	17	29	42	56	11	23	45	5	27	51	21	55	37	33	52	28
Seconds	34	12	44	40	44	20	4	52	56	58	52	8	54	4	12	28	4	4	44	4	0	32

THE PLANETS.

72. All the planets, including the sun and moon, are supposed to have the same absolute daily motion of about 12,000 yojanas. The orbit of the moon being known, the orbits of the other planets are found by (*orbit of moon*) $\times R_m/R_p$, where R_m and R_p are the revolutions in a cycle of the moon and the planet respectively. Whether the elements for the moon were obtained from parallax observations or not is uncertain, but there is no direct evidence

¹ Theon (c. A.D. 380) calculated the *lagna* or 'horoscope' in the same way, but with reference to *temporary hours*. Apparently the Hindus did not at any time employ 'temporary' *muhūrtas* or *ghaṭis*, but see *Albirānī (India i, 338)*, who discusses this interesting topic.

† In modern notation $\cos h = -\tan \varphi \tan \delta$ where $2h/15$ is the length of the day in hours.

³ The *Jyotiṣha Vedāṅga* rule is:—

length of day = $12 \pm 2(183 - n)/61$ *muhūrtas*

where n is the number of days counting from a solstice. The longest day is therefore 18 *muhūrtas* = 14 hours 24 minutes, the shortest day is 12 *muhūrtas* = 9 hours 36 minutes, and the daily increase is $2/61$ *muhūrtas* = 1 minute 34 seconds. The *Paitāmaha Siddhānta* gives 1591 *palas* (= 10 hours 36 minutes 24 seconds) for the shortest day and 3 *palas* for the daily increase.

of such observations. The following table is based on the elements of the later *Sūrya Siddhānta* :—

	A ORBITS.	B SIDEREAL PERIODS.	A ÷ B MEAN DAILY MOTION.
	Yojanas.	Days.	Yojanas.
MOON ¹	324,000	27-321674	11,858-7
MERCURY	1,043,209	87-969702	11,858-7
VENUS	2,664,637	224-608568	11,858-7
SUN	4,331,500	365-258756	11,858-7
MARS	8,146,909	686-997494	11,858-7
JUPITER	51,375,764	4,332-320652	11,858-7
SATURN	127,668,255	10,765-773075	11,858-7

The diameters of the planets other than the sun and moon are generally given in terms of that of the moon. There is little agreement as to the values, some of which are shown in table 4.

The mean motions of the planets are shown in the form of the number of revolutions in a yuga or cycle. For example,² Āryabhaṭa gives the sidereal revolutions in 4,320,000 years as

SUN	4,320,000	MERCURY	17,937,920
MOON	57,753,339	JUPITER	364,224
MARS	2,296,824	VENUS	7,022,388
SATURN	146,564		

Since at the beginning of the Kaliyuga (i.e., sunrise at Ujjain, 18th February, 3102 B.C.), or at the beginning of the Kalpa, all the planets were supposed to be in conjunction, the finding of the mean place at any particular time is not a difficult matter. If t be the time elapsed from the epoch, then having reduced t to sāvana days, d (i.e., having calculated the *ahargana*) the position is obtained by dR/Y .¶

There is no indication as to the means by which the revolutions (R) given were obtained. They first appear in the texts in a fairly accurate form and their appearance coincides with the introduction of the larger cycles—which, indeed, were introduced in order to express the planetary revolutions in integral quantities.

73. SYNODIC REVOLUTIONS.—The synodic revolutions are not usually given in the texts, but they occur in a somewhat disguised form in the *Pañchasiddhāntikā* (Ch. xviii). If P_s is the synodic period of a planet and P_* is its sidereal period and E is the sidereal year we have

¹ The early Hindu astronomers were, of course, well aware of the natural order of the planets, but usually they place them in the 'week-day order.'

² For other values see table 5.

¶ $\frac{Y}{R}$ is the period (P) of the planet, but the Hindus did not generally utilise this ratio as a single element—See, however, the *Pañchasiddhāntikā*, Ch. XVI.

$$\frac{1}{E} = \frac{1}{P_*} \pm \frac{1}{P},$$

where the upper sign is to be taken for a superior and the lower for an inferior planet; and since $P_* = YE/R$ we have $P_e = YE/\pm(Y-R)$ which is the rule implied by Varāha Mihira. His synodic revolutions are given in *saura* days as follows:—

Mars.	Mercury.	Jupiter.	Venus.	Saturn.
768 $\frac{3}{4}$	114 $\frac{6}{9}$	393 $\frac{1}{7}$	575 $\frac{1}{2}$	372 $\frac{2}{3}$

and since 360 *saura* days = 365·256 mean solar days approximately these values become

Mars.	Mercury.	Jupiter.	Venus.	Saturn.
780	115·9	398·8	583·9	378 days.

74. EPICYCLES.—The calculated mean positions of the planets were corrected for the so-called 'first inequality' (that one, namely, which depends on the planet's position relative to the sun), in the Greek fashion, by assuming certain epicyclic motions. The Greek astronomers taught that, while the planet's mean motion could be represented as a movement on the circumference of one circle, called the *deferent*, its actual motion was on the circumference of another circle, called the *epicycle*, whose centre was the mean position on the circumference of the deferent. This is the scheme in broad outline only: it was apparently based on the principle that the motions of a heavenly body must be made up of pure circular motions—a principle that does not appear to have influenced the Hindus.

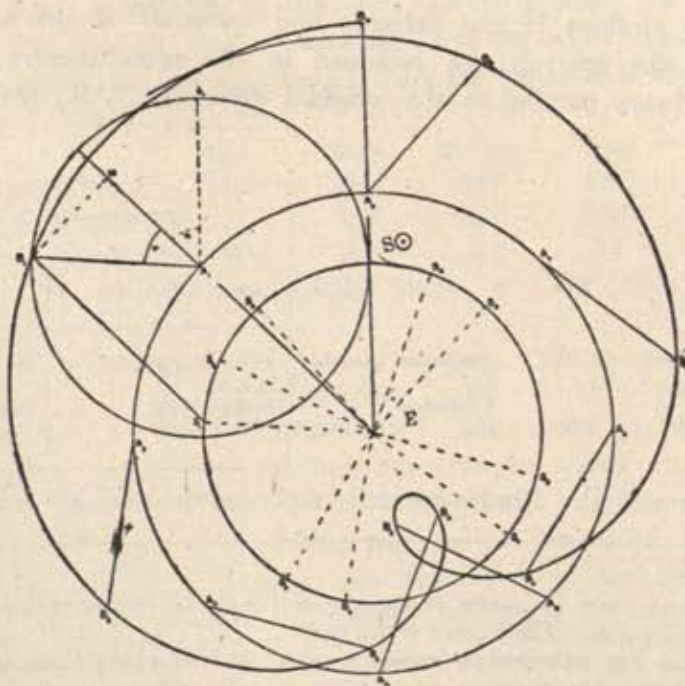


fig. 10.

In figure 10 the epicyclic motion of an outer planet of the type of Mars is roughly represented. The point *E* represents the position of the earth, the

circle $A_0 A_1 A_2$, etc., is the deferent, and the circle $b_1 B_1$ is the epicycle when the mean position of the planet is at A_1 . The epicycle is not drawn for other mean positions, but its radius is marked ($A_2 B_2$, $A_3 B_3$, etc.). The points A_0 , A_1 , A_2 , etc., mark the mean position on the deferent at intervals of 30 degrees, the corresponding positions on the epicycle being B_0 , B_1 , B_2 , etc. The period of revolution of A on the deferent is the sidereal period (P^*) of the planet, and the period of revolution of B on the circumference of the epicycle is the sidereal year (E). At $EA_0 B_0$ the earth, sun and planet are in line: the point B moves from B_0 to B_1 while the point A moves from A_0 to A_1 and we have

$$\frac{\text{angle } B_1 A_1 b_1}{\text{angle } A_1 E A_0} = \frac{1/E}{1/P^*} = 1.8 \text{ in the figure.}$$

From B_1 to B_2 the planet retrogrades and the angle of retrogression is in the figure approximately 25 degrees. The stationary points are determined (fig. 10a) by

$$B\pi/EB = (\text{velocity in deferent})/(\text{velocity in epicycle}) = u/v.†$$

If $S_0 S_1 S_2$, etc., represents the orbit of the sun, (fig. 10a) then $B_0 S_0$, $B_1 S_1$, $B_2 S_2$, etc., represent the distance of the planet from the sun, and, since ES is, with the superior planets,² always parallel to AB (because the period of B is the same as that of S , namely the sidereal year), BS is always equal to EA .

The planet is nearest the earth when in opposition and furthest away when in conjunction.

The superior and inferior planets require different treatment with reference to the relative motions in the deferent and epicycle. If the anomaly (that is the motion in the epicycle) be reckoned in the more modern way from the radius $A_1 b_1$ always parallel to the original direction $A_0 B_0$, then the following scheme holds³ :—

PERIODS OF REVOLUTION.			
		On the deferent.	On the epicycle.
MODERN WAY	{ Superior planets	Sidereal period of planet.	Sidereal year.
	{ Inferior " "	Sidereal year.	Sidereal period of planet.

But the Greeks and the Hindus generally reckoned the anomaly from the directions

† See § 76 g. 10 (a).

² For Mercury and Venus the centre of the epicycle is on the line joining to the mean place of the sun, since in these cases the period of A is the same as that of S .

³ In fig. 10 what may be termed the 'modern anomaly' is $v + u$, while the 'ancient anomaly' is v ; and, since for a superior planet.

$\frac{1}{E} = \frac{1}{P_s} + \frac{1}{P_e}$ or $(P_e + P_s)/P_e = P_s/E$;
and also $(u + v)/u = P_s/E$, we have $v/u = P_s/P_e$. Similarly for an inner planet, as
 $\frac{1}{E} - \frac{1}{P_s} = \frac{1}{P_e}$ and $v - u = \frac{E}{P_s}$ we have $\frac{v}{u} = \frac{E}{P_e}$.

EA_0 , EA_1 , etc., that is from the apogee of the epicycle, and consequently the periods were—

ANCIENT WAY		On the deferent.	On the epicycle.
	Superior planets	Sidereal period of planet.	Synodic period of planet.
	Inferior "	Sidereal year.	Synodic period of planet.

75. THE HINDU SCHEME.—The general explanation of the disturbing causes of the planetary motions is, in the words of the *Sūrya Siddhānta* (ii, 1—4), as follows:—

“Forms of time, of invisible shape, stationed in the zodiac, called *śigrochcha*, *mandochcha* and *pāta*, are causes of the motions of the planets. The planets attached to these beings by cords of air are drawn away by them with the right hand and left hand, forward and backward according to nearness towards their own place. A wind, moreover, called *pravaha*, impels them towards their own points; being drawn away forward or backward they proceed by a varying motion. The so-called *uchcha*, when in the half orbit in front of the planet, draws the planet forward: in like manner, when in the half orbit being the planet, it draws it backward.” The term *mandochcha*, or ‘apex of slowest motion,’ corresponds to the term *aphelion*, while the term *śigrochcha*, or ‘apex of swiftest motion,’ corresponds to the term *conjunction*.¹

In the earlier *siddhāntas* the line of apsides appears to have been considered as fixed, but later a definite motion was given—possibly on the analogy of the motion of the moon’s line of apsides; but on what principle the actual values given were obtained is not indicated. For the positions of apogee or aphelion the following longitudes are given²:—

	Sun.	Mars.	Mercury.	Jupiter.	Venus.	Saturn.
<i>Pāñchasiddhāntika</i>.	...	110°	220°	160°	80°	240°
<i>Brāhmasphuṭasiddhānta</i>.	...	127°	227°	170°	90°	252°
<i>Sūrya Siddhānta</i> .	77°	130°	220°	171°	80°	237°

and the following are the revolutions given to the lines of apsides in 4,320,000,000 years:—

	Sun.	Moon.	Mars.	Mercury.	Jupiter.	Venus.	Saturn.
Brahmagupta	480	488,105,858	292	382	855	653	41
<i>Sūrya Siddhānta</i>	387	488,203,000	204	368	900	535	39

For Saturn the motion of aphelion amounts to about one minute of arc in five thousand years!

The *Pāñchasiddhāntikā* says—“The Sun is the so-called *śighra*,” and in the Hindu system, as in the Greek, the revolution of the conjunction of an inferior planet takes the place of the actual revolution of the planet itself.³

¹ ‘Superior conjunction’ is meant.

² Āryabhaṭa gives 78° for the apogee of the sun. Barth, assuming that this was the result of direct observation, attempted to estimate therefrom the date of Āryabhaṭa’s astronomy.

³ A revolution was considered complete only when the planet had passed through the whole zodiac: this Venus and Mercury are only able to accomplish as they accompany the sun in its apparent annual motion.

75(a). THE TWO EPICYCLES.—The Hindu scheme differs considerably in detail from that of Ptolemy. The object appears to have been the attainment of the correct apparent position of the planet without reference to the representation of its actual motion. As far as information is available we gather that the planet was regarded as actually moving in the deferent, and that the system of epicycles was solely for the purpose of ascertaining the apparent position in the deferent at any time.

The Hindu system involves the use of two different and independent epicycles for each planet (except the sun and moon) and four sets of calculations, and the epicycles, at least in the later works, vary in dimensions with reference to their positions on the deferent. In the *Sūrya Siddhānta* these epicycles are termed *manda paridhi*, or 'epicycle of the apsis,' and *śighra paridhi*, or 'epicycle of conjunction' and their dimensions as given in that work are as follows¹ :—

Dimensions of Epicycles.

	Circumference of <i>manda paridhi</i> = E .		Circumference of <i>śighra paridhi</i> = E_c .	
	Anomaly 0° or 180°.	Anomaly 90° or 270°.	Anomaly 0° or 180°.	Anomaly 90° or 270°.
SUN	14° 0'	13° 40'	....	....
MOON	32° 0'	31° 40'	....	....
MARS	75° 0'	72° 0'	235° 0'	232° 0'
MERCURY	30° 0'	28° 0'	133° 0'	132° 0'
JUPITER	33° 0'	32° 0'	70° 0'	72° 0'
VENUS	12° 0'	11° 0'	262° 0'	260° 0'
SATURN	49° 0'	48° 0'	39° 0'	40° 0'

The change in the dimension of the epicycle is proportional to the sine of the anomaly. If ΔE is the difference as given in the table and θ the anomaly then the dimension at θ is given by $E - \Delta E \sin \theta$, or, if the Hindu sine function is used, by $E - \Delta E \sin \theta / r$. This result is based upon the proportion.

$$\frac{x}{\Delta E} = \frac{\sin \theta}{\sin 90^\circ}$$

where x is the diminution at θ . If

$$e. 360^\circ = E - \Delta E \sin \theta, \text{ or } E - \frac{\Delta E}{\sin 90^\circ} \sin \theta$$

we may term ' e ' the reduced epicycle.

But E and $e360^\circ$ are only apparent dimensions, and the change is probably due to a supposed change in the distance from the centre of the deferent to

¹ Brahmagupta gives: Sun 14° to 13° 40'; Moon 36° 31' to 30° 44'.

the centre of the epicycle, and is connected with the 'second inequality'—due to the excentricity of the orbits.¹

The values of E are for the circumference of the epicycle in terms of the circumference of the deferent. For example the value 72 for Mars means that

$$\frac{\text{the circumference of epicycle}}{\text{the circumference of deferent}} = \frac{72}{360} = \frac{1}{5}$$

or $r_e/r_d = 1/5$ where r_e is the radius of the epicycle and r_d is the radius of the deferent. We shall denote r_e/r_d by e_a or e_c according as the epicycle of the apsis or the epicycle of conjunction is employed.

76. THE EQUATION OF THE CENTRE.—The processes involved in determining the equation of the centre are generally four. If λ denotes the mean position of the planet then the first correction gives $\lambda_1 = \lambda + \epsilon_1/2$ where ϵ_1 is the equation arrived at by employing the epicycle of conjunction; the second correction gives $\lambda_2 = \lambda_1 + \epsilon_2/2$ where ϵ_2 is the equation derived by employing the epicycle of the apsis; $\lambda_3 = \lambda + \epsilon_3$ where again the epicycle of the apsis is employed; and finally $\lambda_4 = \lambda_3 + \epsilon_4$ where the epicycle of conjunction is again employed.

The calculations may be summarised thus:—

$$\begin{aligned} \text{(i)} \quad \lambda_1 &= \lambda + \epsilon_1/2 \quad \text{where} \quad \sin \epsilon_1 = \frac{e_c \sin v_0}{\sqrt{e_c^2 + 2e_c \cos v_0 + 1}} \\ \text{(ii)} \quad \lambda_2 &= \lambda_1 + \epsilon_2/2 \quad \text{,,} \quad \sin \epsilon_2 = \frac{e_a \sin v_1'}{e_c} \\ \text{(iii)} \quad \lambda_3 &= \lambda + \epsilon_3 \quad \text{,,} \quad \sin \epsilon_3 = \frac{e_a \sin v_2'}{e_c} \\ \text{(iv)} \quad \lambda_4 &= \lambda_3 + \epsilon_4 \quad \text{,,} \quad \sin \epsilon_4 = \frac{e_c \sin v_3}{\sqrt{e_c^2 + 2e_c \cos v_3 + 1}} \end{aligned}$$

where $v_0 = \lambda_0 - \lambda$; $v_3 = \lambda_3 - \lambda$; $v_1' = \lambda_1 - \lambda$; and $v_2' = \lambda_2 - \lambda$; and consequently

$$v_3 = v_0 - \epsilon_3 \quad \text{and} \quad v_2' = v_1' - \epsilon_2/2.$$

The calculations according to the *Pañchasiddhāntikā* (ch. xvii) may be expressed in the following form. The later texts give rather more complicated but not essentially different rules, of which a specimen will be exhibited in due course.

	ii.	iii.	iv.
$a_1 = e_c \sin v$	$a_2 = e_c \sin v_1'$	$a_2 = e_c \sin v_2'$	$a_4 = e_c \sin a_3$
$b_1 = e_c \cos v$	.....	.....	$b_4 = e_c \cos v_3$
$c_1 = \sqrt{a_1^2 + (r_d + b_1)^2}$	.....	.....	$c_4 = \sqrt{a_4^2 + (r_d + b_4)^2}$
$\epsilon_1 = \sin^{-1} a_1 r_d / c_1$	$\epsilon_2 = \sin^{-1} a_2$	$\epsilon_3 = \sin^{-1} a_3$	$\epsilon_4 = \sin^{-1} a_4 r_d / c_4$
$\lambda_1 = \lambda + \epsilon_1/2$	$\lambda_2 = \lambda_1 + \epsilon_2/2$	$\lambda_3 = \lambda + \epsilon_3$	$\lambda_4 = \lambda_3 + \epsilon_4$

¹ The term 'oval' has been applied to the epicycle in this connexion but is not altogether appropriate.

Theoretically, at least, the origin of the change in dimension of the epicycle is known. In the case of the moon the effect of the second inequality was always to increase the absolute value of the first one, particularly in the quadratures. "The obvious inference was," writes J. L. E. DREYER (*Planetary Systems*, p. 193), "that the radius of the epicycle appeared to be of variable length, greater in quadrature than in syzygy." But Ptolemy made the centre of the epicycle move on an excentric so that its distance from the earth varied and consequently so did the apparent dimensions of the epicycle. The excentric appears comparatively late in India. See the *Siddhānta Śiromani*, G. v, 7f.

The Hindu method as applied to a superior planet is illustrated in figure 10. The period of the epicycle is the synodic period of the planet (reckoning in the Greek fashion always from EA) and that of the deferent is the sidereal period of the planet. We have

$$A_0 EA_1 / MA_1 B_1 = P_s / P_* \text{ or } \frac{u}{v} = \frac{P_s}{P_*}.$$

The problem is to calculate $\epsilon = \angle B_1 EA_1$. The line $B_1 M = a$ is perpendicular to EA_1 while $A_1 M = b$. Now $EM^2 + a^2 = EB_1^2$

or $(r_d + b)^2 + a^2 = EB_1^2$ and $\frac{a}{EB_1} = \sin \epsilon$;

but $b = r_e \cos v$ and $a = r_e \sin v$, therefore

$$(i) \sin \epsilon = \frac{r_e \sin v}{\sqrt{(r_d + r_e \cos v)^2 + r_e^2 \sin^2 v}} \\ = \frac{e \sin v}{\sqrt{1 + e^2 + 2e \cos v}} \text{ where } e = \frac{r_e}{r_d}$$

A simpler formula is

$$(ii) \tan \epsilon = \frac{B_1 M}{EM} = \frac{r_e \sin v}{r_d + r_e \cos v} \\ = \frac{e \sin v}{1 + e \cos v} \text{ or } \frac{\sin v}{1/e + \cos v},$$

but the Hindus, like the Greeks, did not employ the tangent function.

The maximum value of ϵ occurs when EB is a tangent to the epicycle, that is when AB is at right angles to EB ; and then $\sin \epsilon = r_e / r_d = e$, $v = 90^\circ + \epsilon$.¹

76(a). The following calculation for the equation of the centre of Venus is based upon the later *Sūrya Siddhānta* elements² :—

The equation of the centre for Venus.

Given mean longitude	8° 18' 13'.
Longitude of conjunction	10° 21' 50' : anomaly $v = 2^\circ 3' 37'$.
Longitude of apsis	2° 19' 52' : anomaly $v' = 5^\circ 18' 35'$.
Epicycle of conjunction	E_c varies from 260° to 262° . Difference $\Delta E_c = 2'$.
Reduced epicycle $e_c = (rE_c - \Delta E_c \sin v) / 360 r$.	
Epicycle of apsis	E_a varies from 11° to 12° . Difference $\Delta E_a = 1'$. Reduced epicycle $e_a = (rE_a - \Delta E_a \sin v') / 360 r$.

	i. For equation of conjunction.	ii. For equation of apsis.	iii. For equation of apsis.	iv. For equation of conjunction.
Longitude	$\lambda = 8^\circ 18' 13'$	$\lambda_1 = 9^\circ 1' 17'$	$\lambda_2 = 9^\circ 1' 28'$	$\lambda_3 = 8^\circ 18' 36'$
Anomaly	$v = 2^\circ 3' 37'$	$v_1 = 5^\circ 18' 35'$	$v_2 = 5^\circ 18' 24'$	$v_3 = 2^\circ 3' 14'$
$\sin v$	$\sin v = 3090'$	$\sin v_1 = 689'$	$\sin v_2 = 691'$	$\sin v_3 = 3069'$

¹ Since $v = 90 + \epsilon$ we have

$$\tan \epsilon = \frac{e \cos \epsilon}{1 - e \sin \epsilon} \text{ or } \sin \epsilon = e (1 - \sin^2 \epsilon) / (1 - e \sin \epsilon)$$

of which a solution is $\sin \epsilon = e$.

² See *J.A.O.S.*, 1858, 213f.

	i. For equation of conjunction.	ii. For equation of apsis.	iii. For equation of apsis.	iv. For equation of conjunction.
$\cos v$	$\cos v = 1527'$	$\cos v_1' = 3369'$	$\cos v_2' = 3368$	$\cos v_2 = 1548'$
Corrected epicycle e	$e_c = 723$	$e = 0328$	$e = 0328$	$e = 723$
$a = e \sin v$	$a_1 = 2226'$	$a_2 = 22.3'$	$a_2 = 22.6'$	$a_4 = 2218'$
$b = e \cos v$	$b_1 = 1104'$	$b_2 = 110'$	$b_2 = 110.4'$	$b_4 = 1119'$
$c = \sqrt{a^2 + (r + b)^2}$	$c_1 = 5058'$	$c_2 = 3548'$	$c_2 = 3458'$	$c_4 = 5067'$
$\sin^{-1} ar / c = \epsilon$	$\epsilon_1 = 26^\circ 7'$	$\epsilon_2 = 0^\circ 22'$	$\epsilon_2 = 0^\circ 23'$	$\epsilon_4 = 25^\circ 59'$
Corrected longitude	$\lambda + \frac{\epsilon_1}{2} = 9^\circ 1' 17''$	$\lambda_1 + \frac{\epsilon_2}{2} = 9^\circ 1' 28''$	$\lambda + \epsilon_2 = 8^\circ 18' 36''$	$\lambda_3 + \epsilon_4 = 9^\circ 14' 35''$

The process, it will be seen, is the same as that of the Pañchasiddhāntikā except that variable epicycles have been introduced.

The only process required in the cases of the sun and moon is the 'correction for the apsis,' which may be represented by $\tan \epsilon = (e \sin v)/(1 + e \cos v)$. The early texts give tabular results by means of which the calculations may, to some extent, be avoided. These, however, are not very complete and are not altogether in agreement.¹

Retrogression.—In figure 10 (a) if $B\beta$ or $B'\beta'$ ($= r. \Delta v$ or $r. \Delta v'$) is the arc on the epicycle passed over in time Δt , r being the radius of the epicycle, and $v = CAB$ or CAB' being the anomaly, then if $B\beta$ is small, the angle $B\beta\eta = ABB'$ and $\beta\eta = B\beta \cos ABB'$. But $\beta\eta/EB = \alpha\alpha'/R$ where R is the radius of the deferent, therefore

$$\begin{aligned} \alpha\alpha' &= R. \beta\eta/EB = R. \frac{B\beta}{EB} \cos ABB' \\ &= \frac{R. r. \Delta v. B\pi}{rEB} = \frac{B\pi}{EB} R. \Delta v \text{ or } \frac{B\pi}{EB} R. \Delta v. \end{aligned}$$

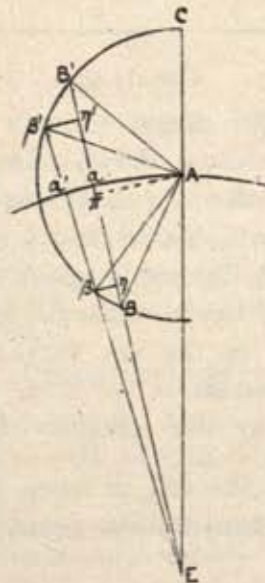


Fig. 10(a)

¹ According to Jacobi and Sewell (*Epigraphia Indica*, i, 441 and xiv, 10) $\sin \epsilon = e \sin v$ where e is the 'reduced epicycle' (§ 75a) is generally employed.

If $\alpha'\alpha$ is equal and opposite to the motion in the deferent, that is if

$$R \cdot \Delta u - \frac{B\pi}{EB} \cdot R \cdot \Delta v = 0, \text{ then } \frac{B\pi}{EB} = \frac{\Delta u}{\Delta v}$$

and B is a 'station' of the planet and $2AEB$ is the angle of retrogression. Instead of $B\pi$ the *Sūrya Siddhānta* gives 'the difference between the hypotenuse and the radius,' that is $R - EB$, or $EB' - R$.

The text then gives the angles ABE for the stationary points B as follows:—

Mars.	Mercury.	Jupiter.	Venus.	Saturn.
16	36	50	17	65

from which the angles of retrogression AEB may easily be calculated if r/R be known. The Hindu texts do not give this value definitely, but it is approximately e , calculated for the epicycle of 'conjunction.'

77. LATITUDE.—The node, Rāhu, is said to cause the deviation of the planets in latitude (SS. ii, 6). The later rule for latitude given is

$$\beta = \frac{\beta' \sin \Delta\lambda}{r/r'}$$

where β' is the maximum deviation as seen from the earth at its mean distance, r is the true distance of the planet from the earth, and r' is its mean distance, and $\Delta\lambda$ is the distance of the planet from its node. The deviations are given as follows:—

	Moon.	Mars.	Mercury.	Jupiter.	Venus.	Saturn.
Pañchasiddhāntikā	4° 0'	1° 41'	2° 15'	1° 41'	2° 15'	2° 15'
Sūrya Siddhānta	4° 30'	1° 30'	2° 0'	1° 0'	2° 0'	2° 0'

PARALLAX.

78. In works of the earlier period there is no reference to parallax and there is no real attempt to measure the distances of the sun, moon and other planets; while in later works the subject of parallax occurs only in connexion with eclipses. The later *Sūrya Siddhānta* treats of parallax in longitude (*harija*, Gk. *οριζων*), and parallax in latitude (*avanati*, 'depression'): it states that there is no solar parallax in latitude when the ecliptic is a vertical circle, and also that there is no parallax of the sun in longitude when that planet is in the meridian. This latter statement is not true, as Whitney points out,¹ unless the ecliptic is also bisected by the meridian. (See §68 (g)).

The horizontal parallax of the sun or moon is assumed to be equal to the motion of the planet during four *nādikās*, or one-fifteenth part of a day. We thus have

$$\pi = (\text{daily motion of sun})/15 = \theta_s/15 \text{ for the horizontal parallax of the sun,}$$

$$\pi' = (\text{daily motion of moon})/15 = \theta_m/15 \text{ for the horizontal parallax of the moon.}$$

¹ *JAOS.*,—1858, p. 286.

where θ is the angular motion of the planet during the day.¹ Since $\theta = s/r$ nearly, where r is the radius of the orbit and s is the arc traversed in one day and since, in the Indian system, s is constant for all planets and is equal to 12000 yojanas,² we have $s/15 = 800$ yojanas, which is the Hindu value of the earth's radius; and π becomes equal to $s/15r = \rho/r$ which is approximately true when r is great compared with ρ .

Sometimes the difference between the parallax of the sun and moon is given. Thus the parallax in latitude is given in forms that may be expressed by

$$\begin{aligned}\pi_{\beta}' - \pi_{\beta} &= (\theta_m - \theta_s) (\sin z_s)/15 = 49' (\sin z_s)/r \\ &= (\sin z_s)/70\end{aligned}$$

where $\sin z_s$ is the *drikshepa* (see page 76).

The rule for parallax in longitude may be expressed by

$$\pi_{\lambda} = \pi \cos z_s \sin (\lambda_Y - \lambda)$$

where λ is the longitude of the star and λ_Y is the longitude of the nonagesimal.⁴

The Hindu rules for parallax may then be summarised thus:

- (i) Horizontal parallax $\pi = \theta/15$
- (ii) Parallax in latitude $\pi_{\beta} = \pi \sin z_s$
- (iii) Parallax in longitude $\pi_{\lambda} = \pi \cos z_s \sin \lambda_Y - \lambda$

while the corresponding approximately correct formulae are

- (i) $\sin \pi = \rho/r$
- (ii) $\pi_{\beta} = \pi \sin \beta_z \sin (\gamma - \beta)/\sin \gamma$
- (iii) $\pi_{\lambda} = \pi \cos \beta_z \sin (\lambda_z - \lambda)/\cos \beta$

where λ and β are the star's geocentric longitude and latitude, and λ_z and β_z are the longitude and latitude of the zenith, and

$$\tan \gamma = \tan \beta_z / \cos (\lambda_z - \lambda).$$

We then have

- (i) $\theta/15 = \rho/r$ nearly;
 - (ii) $\pi \sin z_s = \pi \sin \beta_z \sin (\gamma - \beta)/\sin \gamma$;
 - and (iii) $\pi \cos z_s \sin (\lambda_Y - \lambda') = \pi \cos \beta_z \sin (\lambda_z - \lambda)/\cos \beta$;
- and as β is generally considered negligible in these Hindu calculations we have

$$z_s = \beta_z \text{ and } \sin (\lambda_Y - \lambda') = \sin (\lambda_z - \lambda)$$

where λ' is the apparent longitude; and as a matter of fact the zenith distance (z_s) of the nonagesimal is equal to the latitude of the zenith (β_z), and the longitudes of the zenith (λ_z) and the nonagesimal (λ_Y) are the same.

LUNAR ECLIPSES.

79. DIAMETER OF THE SHADOW.—In figure 11 we have

- (i) the angle $TEM = PTE - POE = PTE - Q'ES = PTE - (QES - QEQ')$

¹ The mean values of the daily motion usually given are: moon $13^{\circ} 10' 34''$; sun $59' 8''$, which make $\pi' = 52.7$ and $\pi = 3.9$; but the texts give no actual parallax values explicitly. The *Sūrya Siddhānta* implies $\pi' = 53.3$ and $\pi' - \pi = 49'$.

² The *Sūrya Siddhānta* value is 11,858.7 yojanas.

⁴ In the texts the meridian ecliptic point is sometimes substituted for the nonagesimal point.

where S , E , and M are the centres of the sun, earth and moon respectively, EP and SQ are perpendiculars to OPQ , TM is

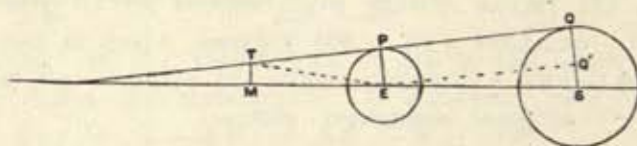


Fig. 11.

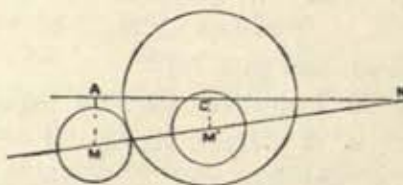


Fig. 12.

perpendicular to OS , and EQ' is parallel to PQ . If R_s , R_m , R_e , R , denote the radii of the shadow, the moon, the earth and the sun respectively, and if r_m and r_s denote the distances of the centres of the moon and sun from the centre of the earth, then, since the angles are all small, we obtain from (i)

$$(ii) R_e = R_s - R_s (R_m/R_s - 1) r_m/r_s.$$

The *Paulīśa Siddhānta* simply assumes that $R_e = 38'$; the old *Sūrya Siddhānta* gives the rule in the form

$$2R_e = 36' - 36' \frac{r_m}{r_s} \frac{90}{276}$$

which¹ is obtained from (ii) by making

$$R_s = 18' \text{ and } R_m = 73.2';$$

while the modern *Sūrya Siddhānta* gives it thus—

$$R_e = R_s m_m + R_s m_s (R_m/R_s) - R_s m_s (R_m/R_s)$$

where m_m and m_s are the ratios of the true daily motions to the mean daily motions of the moon and sun respectively. This rule implies two assumptions, neither of which is strictly accurate: (a) that the ratio of the true daily motion to the mean daily motion is equal to the ratio of the mean distance to the true distance; (b) that $R_m/R_s = r_m/r_s$, which implies that the mean apparent values of the diameters of the sun and moon are equal.

DURATION.—In figure 12 let M be the centre of the moon when about to enter the shadow, C the centre of the shadow whose radius is R_e ; let AN be the ecliptic and MN the moon's path. If v is the velocity with which the moon travels from M to M' then the duration of the eclipse is

$$(iii) t = 2MM'/v = \frac{2 \cdot 60''}{\theta_m - \theta_s} \sqrt{(R_e \pm R_m)^2 - \beta^2}$$

¹ Here the values are in lengths and the corresponding value of the moon's orbit would be

$$\frac{324000}{800 \div 18} = 7290 \text{ (see table 7).}$$

To reduce to minutes of arc we must therefore multiply by $360 \times 60 \div 7290$.

where β is the moon's latitude at the time of opposition, and there are 60 nādikās in a day

For the time between the first and last moments of internal contact we have

$$(iv) \ t = \frac{2}{v} \sqrt{(R_e - R_m)^2 - \beta^2} \dagger$$

The *Pauliṣa Siddhānta* gives rule (iv) in the form

$$t = \frac{2}{v} \cdot \frac{21}{5} \sqrt{4(5 - \Delta\lambda)(10 - (5 - \Delta\lambda))}$$

Since

$$\beta/240' = \sin \Delta\lambda / \sin 90^\circ,$$

where 240' is the moon's greatest latitude, and $\Delta\lambda$ is the difference in longitude between the moon and its node; and since

$$\sin \Delta\lambda / \sin 10^\circ = \Delta\lambda / 10,$$

nearly, where 10° is the limit from the node for a total eclipse; we have

$$\beta = 240' \times 21 \times \Delta\lambda / 10 \times 120 = 21 \Delta\lambda / 5,$$

where 21' is the sine of 10 degrees and 120' is the sine of 90 degrees according to the *Pauliṣa Siddhānta* tables (see table 11). We now have

$$t = \frac{2}{v} \sqrt{21^2 - \left(\frac{21 \Delta\lambda}{5}\right)^2} = \frac{2}{v} \frac{21}{5} \sqrt{(5 - \Delta\lambda)(10 - (5 - \Delta\lambda))}.$$

These rules appear to ignore the variation in latitude that takes place, but the *Sūrya Siddhānta* directs us to find the value of the moon's latitude at first contact from the value of t , to substitute this value and repeat the process till t is constant: that is, as we know the longitude of the moon at the time of first contact, we calculate the latitude and substitute the value so obtained and repeat the process until the results no longer differ.

80. SOLAR ECLIPSES.—Apart from the preliminary calculations involving parallax very little is given about solar eclipses. The *Pauliṣa Siddhānta* gives the time of duration as

$$t = \frac{3}{4} \sqrt{64 - \Delta\lambda^2}$$

which appears to be obtained from the usual rule $\frac{2}{v} \sqrt{(R_e + R_m)^2 - \beta_m^2}$; for $\beta_m = \frac{9}{2} \Delta\lambda$ approximately, and $R_e + R_m = 36'$, and $v = 720/60$ is the difference between the mean motions of the moon and sun in a nādikā.

81. THE PROJECTION OF ECLIPSES.—“Since, without a projection (*chedyaka*), the precise difference between two eclipses are not understood, I shall proceed to explain the exalted doctrine of the projection,” writes the author of the *Sūrya Siddhānta*.²

In figure 6 let X be the position of the moon at the moment of opposition, then NXS is the circle of position and marks the north and south direction with reference to the moon, while the circle XE' at right angles to NXS

† The time rules (iii) and (iv) may be obtained direct from the modern rule

$$a = \sqrt{(\beta - bt)^2 + (m - s)^2} t^2,$$

where b is the rate of the moon's motion in latitude, and m and s are the rates of the sun's motion in longitude, by making $a = R_e \pm R_m$ and solving for t .

Formulae (iii) and (iv) neglect bt but the *Sūrya Siddhānta* rule is an attempt to account for this term.

² For the Greek treatment of this topic see the *Almagest*, VI, xi-xiii.

CHAPTER X.

Conclusion.

82. The chief phases of the history of Hindu astronomy are connected with the Vedas, the Vedāṅgas and the mediæval text books, or siddhāntas. Vedic astronomy is naturally of the unscientific order, the Vedāṅga astronomy is formal but crude, while the astronomy of the later siddhāntas is, on the whole of a very high intellectual order. The more important items of the available evidence that illustrate these phases have been given in the previous chapters, but there are certain matters to which further reference may be made,—for example, the relationship of the Vedāṅga astronomy to the current thought of the time, the exotic astronomy of the later period, the controversy regarding the antiquity of the Vedas, the evolution of astrology and the astronomical deities of India.

83. It will be recalled that the *Jyotisha Vedāṅga* and similar works very strangely omit all reference to the planets and their motions, while in the epics and other popular works of the period such references, informal though they be, are numerous. Let us assume that the Vedāṅgas, Jātakas, the epics and Purāṇas more or less overlapped chronologically, and as a matter of convenience let us fix the whole period embraced by these works as from 400 B.C. to A.D. 400. We are then forced to one of two conclusions, namely, that either (a) all the more advanced astronomical notions displayed in the popular works are late additions or interpolations; or (b) the knowledge of astronomy indicated in the popular works was in advance of that exhibited in the formal astronomical works. The first alternative (a) seems to be untenable, since the references to the planets, &c., in the popular works are far too numerous to be easily explained away, and their mode of occurrence, in some cases at least, does not suggest interpolation; and, of course, in the west the knowledge in question was widely diffused during this (assumed) period. We are thus led to the second of the alternatives (b), and to the fairly legitimate deduction therefrom that the Vedāṅga astronomy was of the traditional order, and that the professional astronomer had not kept pace with the time.¹ This conclusion, that the Vedāṅga astronomy was not thoroughly representative of the period, depends, however, upon the assumption made as to the chronology of the works in question.

84. The second point is perhaps more important. The facts and the chronology are, within reasonable limits of error, firmly established. About A.D. 450 the Hindu teachers began to expound a new astronomy that had been received from the west. The Hindus of this period were not obsessed by tradition, they were in a plastic state of mind and their attitude in intellectual and æsthetic matters was one of rather eager receptivity. All that

¹ The same has happened in India in quite modern times. Even now the so-called orthodox teacher generally prefers to stick to traditional lore, and he often displays considerable ingenuity in trying 'to save the phenomena'. In Europe, not so long ago, false traditional teaching of astronomy was made almost a matter of faith.

appeared good was welcomed, and, partly in consequence of this intelligent attitude, there began for India a period that has been appropriately designated its 'golden age.' In striking contrast is the beginning, at the same period, of the 'dark ages' in Europe, where a bigoted hierarchy discredited the inestimable gifts of the heathen Greeks. India welcomed and assimilated as much of the Greek teaching as could reach her; but from Alexandria to Ujjain was in those days a long journey, and the transmission of knowledge was hindered in many ways, so that finally the Greek knowledge was received in India in a somewhat frayed condition.

There is an interesting corollary to this. Tradition says that the Arabs first received their knowledge of scientific astronomy from India,¹ and, it is possible that the Arabs were thus instigated to acquire knowledge from the Greek writers also. Later, Europe received from the Arabs the teaching it had spurned so long before.

85. The investigations of H. Jacobi and B. G. Tilak are worthy of special mention. By means of certain quasi-astronomical passages they independently came to the conclusion that portions of the early texts were composed some 4,500 years before the Christian era. Jacobi is one of the most learned of the European orientalists, and his opinion is, in itself, of extreme value; but we are compelled to reject some of his conclusions. Further, if my suggestion that the nakshatras formed, at least in some cases, merely a relative scale whose initial point was an equinox or solstice, be of any value, then the arguments of Jacobi and Tilak generally fail.

86. In all countries, in the early stages of intellectual development, the connexion between astronomy and religion has been intimate. For India the history of this connexion is particularly interesting and the literature relating to it is sometimes beautiful. In comparatively late times an exotic astronomical cult and an exotic astrological system tended to obscure the historical development; but the cult never became predominant and the scheme of astrology was altogether subordinated to the spirit of Hinduism. It is impossible to elaborate these themes in the present volume but the summary accounts of Hindu astronomical deities and astrology in India appended may serve a useful purpose if they draw attention to these interesting topics and the important part they have played in the progress of civilisation.

¹ See also pages 47 and 49.

APPENDIX I.

Astrology in India.

Astrology has played an important part in the past and its present influence is enormous over that portion of the human race whose view of the universe may be characterised as anthropocentric and whose capacity for credulity is not very definitely limited. Its importance as a factor in the development (or retardation) of civilisation has been recognised to a limited extent. Bouché-Leclercq, Cumont, Housman, von Oefele, Nallino and others have dealt with astrology in Europe, Egypt, Mesopotamia and among the Muslims generally; but with reference to India the only general account is Thibaut's very brief summary in the *Grundriss der Indo-Arischen Philologie*. The following note is merely an attempt to draw attention to a subject which, particularly in India, has influenced thought generally and astronomy specifically.

Recent researches into the early history of civilisation seem to indicate that astrology developed at a very early period and that its roots were deeper planted and its branches more widely spread than was formerly held; but we must accept with caution wide and vague conclusions that are not supported by direct evidence. The astrology that von Oefele writes of, for example, is planetary astrology, and he states that "even in the most remote ages the periods of evolution peculiar to the seven planets had been studied." But such a statement cannot be accepted without question. As based upon our knowledge of Babylonian and Egyptian astronomy it might be accepted with modification; but such a statement is not needed as a postulate unless it is assumed that astrology was necessarily planetary astrology in its earlier stages. It would not be difficult to formulate a genealogy of astrology commencing with the animistic vogue of the primitive mind and ending at the stage when the planetary motions had been observed with fair accuracy. For undoubtedly astrology exhibits a phase of the tendency of the primitive mind to endow inanimate objects with spiritual life, and it has little concern with the astronomical discoveries of the last two thousand years.

In studying the earliest records of Indian literature and science we are impressed with the absence of unambiguous records of the planets, and it is generally conceded that planetary astrology was an importation from the west. But this absence of official record may only mean that the older Indian hierarchy rejected astrological principles, for there is evidence in the early popular literature of a fairly wide diffusion of astrological practice. The early Buddhist texts condemn such practice with reason, for it did not square with the fundamental principles of Buddhism; and possibly this attitude influenced the Brahmans also. We do, indeed, find, in the Atharva Veda for example, notices and indications of practices in Hindu literature of what might well have developed into formal astrology; but it is only with the decay of Buddhism in India that such formal astrology becomes prevalent.¹

¹ This is possibly merely a chronological coincidence. Later Buddhism itself absorbed certain astrological notions.

The nakshatra list of the Atharva Veda is apparently of an astrological character. It occurs in the seventh section of book xix and is as follows:—

1. Seeking favour of the twenty-eight-fold (?) wondrous ones, shining in the sky together, ever-moving, hasting in the creation, I worship with songs the days, the firmament.

2. Easy of invocation for me the Kṛittikās and Rohiṇī; be Mṛigaśīras excellent, Ārdrā healthful; be the two Punarvasus pleasantness, Pushya what is agreeable, the Āśleshas light, the Maghās progress.

3. Be the former Phalgunis and Hasta here auspicious; be Chitrā propitious, and Svāti easy for me; be the two Viśākhās bestowal, Anurādhā easy of invocation, Jyeshthā a good asterism, Mūla uninjured.

4. Let the former Āshādhās give me food; let the latter ones bring refreshment; let Abhijit give me what is auspicious, let Śravaṇa (and) the Śravishtās make good prosperity.

5. Let Śatabhishaj (bring) to me what is great widely; let the double Proshthapadās (bring) to me good protection; let Revatī and the two Āsvayuj (bring) fortune to me; let the Bharanīs bring to me wealth.

But this is not planetary astrology, and a considerable period elapses before the planets are introduced into the rather crude astronomical magic that appears to have prevailed in post-vedic times. A very interesting but comparatively late fragment from Khotan, written in debased Sanskrit, seems to couple up the later formal astrology with the magical formularies of the Atharva Veda. What is intelligible of this fragment¹ reads as follows:

"A formula of medical herbs..... In this respect effective are Chitrā, Mṛigaśīrā, Śravaṇā, Nidhāna, Punarvasu, Svāti, Śatabhishā.....of those who abandon disputes, quarrels, knives (?) and.....rites. Causers of misfortune are Kṛittikā, Phalgunī, Āshādhā,rough works, having made a firm path. Causers of success in this respect are Pūrva-phalgunī, Pūrva-āshādhā, Pūrva-bhadrpadā.....arrangers to go on a secret path are Ārdrā and Dhanishthā in combination. One may do here all fierce rites,.....here firm, foremost friends are Āśleshā and Jyeshthā. If Utterā-Bhadrpadā be here the third (?), let him do.....for the benefit of living beings, according to circumstances, having known, and various wise men.

The fourteenth day again has Yama for its deity: he should proceed to act as in the former case.....

The shadow turns round, and here Āśvinī leads the night, but Anurādhā the sun towards the southern quarter.....by Suras (and) Rishis thou art encouraged, and in this month (and) field by Rākshasas, men, serpents (and) Yakshas. Vṛiśchika

Now the Rishi Kharuṣṭa addressed the whole congregation, which stood with folded hands, and said 'you have seen, heard, understood the fields, hours (*horā*), signs, positions, progresses, revolutions; and likewise.....the motions of nakshatras and planets (*graha*); are you satisfied and content or not?' Now then, all, bowing with folded hands, spoke thus: 'Thou art the preceptor of all the Devas, the best sage in the world of Suras and Asuras, unlike any other,.....a well-wisher of all living beings, possessed of all eminences, pastmaster in all virtues, endowed with an equal range of the three periods of time, nor has any other such knowledge as thou, to give instruction with regard to nights, days, moments, nakshatras, planets, half-months, months.....'"

This interesting fragment, although found beyond the borders of India proper, is Indian (probably Buddhist) in character and language and appears to belong to an intermediate stage in astrological lore and practice.

¹ *Manuscript Remains of Buddhist Literature found in E. Turkistan.* Vol. I, pp. 121—125. The translation is admittedly unsatisfactory.

The great Indian works on formal astrology are Varāha Mihira's *Bṛihat Saṃhitā* and his *Bṛihaj Jātaka*; and it is in the introduction to the latter (consisting of the first two chapters) that the part in which we are particularly interested, the *horā tantra* proper, occurs. Since the time of Varāha Mihira (sixth century A.D.) no changes of fundamental importance have been made in this science. The following notes summarise the contents of his *Bṛihaj Jātaka* :—

He invokes the aid of the Sun (1), refers to previous works¹ and to the difficulty of the task (2). The signs of the zodiac are connected with the nakshatras and the term 'sign' is defined (4). The western pictorial representations of the signs are detailed (5). The planets as rulers of the signs and of the novenaries and duodenaries (6), and of the terms or limits of the signs (7) are explained. The Greek names of the signs (8) and definitions of the term 'decan', 'novenary', 'duodenary', degree and 'horā' are given (9). Day and night (10) harmful and favourable, male and female, movable and fixed signs are enumerated (11). The exaltations and dejections of the planets (13) and their most auspicious positions and the planetary domiciles are explained (14). The influence of each house (15-16) and the terms applied to the several houses (17-18) and the values of the signs according to their position in the diagram are given (19), together with a rough table of oblique ascensions (19). The chapter ends with a list of the colours attached to the signs and a definition of the term 'vesi' (20).

Chapter II gives the values of the planets (1), their names (2-3), their colours (4-5), the quarters they rule (5), their sex and elements (6), the castes they influence (7), descriptions of persons of each planet (8-11), the places over which they rule (12), their metals, etc. (12). Then are discussed the aspects of the planets (13), their friendly or unfriendly relations with each other (15-18), and their favourable positions (19-20).

The remainder, and by far the greater portion of the book, applies the notions already given to problems relating to birth, death, length of life, vocations, king-ship, etc. There are also chapters on particular configurations, lost horoscopes, etc.

¹ He mentions the following authorities Maya (vii, 1; xii, 6), Yavanāchārya (vii, 1; viii, 9; xi, 1; xii, 6; xxi, 3), Satyāchārya (ii, 15; vii, 9, 10, 11; xii, 2; xxi, 3), Vishṇu Gupta (vii, 7; xxi, 3), Devaswāmī (vii, 7), Siddhasena (vii, 7), Jīva Śarma (vii, 9; xi, 1) Piṇḍayā (vii, 7, 8, 11, 12, 13), Maniṭṭha (vii, 1) Śaktipūrva (vii, 1), Prithu (xxv, 13).

The following tables give the principal elements of Varāha Mihira's astrology :—

1. Houses.

	Designations (i, 16-18).	Influencing (i, 15-16).
I	Horā, Lagna	The Body Strength.
II	Paṇaphara	Relatives Wealth.
III	Āpoklima	Brothers Valour.
IV	Hibuka	Friends Home.
V	Trikopa, Paṇaphara	Sons
VI	Āpoklima	Enemies Injury.
VII	Jāmitra	Wives
VIII	Paṇaphara	Death Weakness.
IX	Āpoklima	Morality Religion.
X	Meshūrana, Karma	Dignity Honour.
XI	Paṇaphara	Income Gain.
XII	Āpoklima¶	Expenditure Loss.

Houses I, IV, VII and X are also designated Kṇṭhaka ('pointed'), Chatusrasra ('square'), Kendra ('central').

2. The Signs.

		Names (i, 5f. 8).	Colours (i, 20).	Sex (i, 11).	Influence (i, 11).	(i, 10).	(i, 11).
*1	ARIES . .	Mesha, Kriya†	Red	Male	Harmful	E. Night	Movable.
2	TAURUS . .	Vṛisha, Tāvuri	White	Female	Good	S. Night	Fixed.
3	GEMINI . .	Mithuna, Jituma	Yellow	Male	Harmful	W. Night	Common.
4	CANCER . .	Karka, Kulira .	Pale red	Female	Good	N. Night	Movable.
5	LEO . .	Simha, Laya .	Smoky	Male	Harmful	Day	Fixed.
6	VIRGO . .	Kanyā, Pāthana	Variegated	Female	Good	Day	Common.
7	LIBRA . .	Tulā, Juka .	Black	Male	Harmful	Day	Movable.
8	SCORPIO . .	Vṛiśchika, Kaurpyā,	Golden	Female	Good	Day	Fixed.
9	SAGITTARIUS . .	Dhanus, Tauk-shika.	Tawny	Male	Harmful	Night	Common.
10	CAPRICORNUS . .	Makara, Ānokero	Grey	Female	Good	Night	Movable.
11	AQUARIUS . .	Kumbha, Hrid-roga.	Mongoose	Male	Harmful	Day	Fixed.
12	PISCES . .	Mina, Itthya .	White	Female	Harmful	Day	Common.

* The Hindus numbered the signs 1 to 12, not as the Arabs did 0 to 11.

† The Greek names of the signs have already been given (page 40).

¶ Certain of these Greek terms have already been given (page 39). Of the others *apanaphora* 'succeedent' *aroklima* 'cadent', *Aupogion* 'inferior culmination', *mesouranema* 'superior culmination', are regular astrological terms.

3. The Planets.

	Names (ii, 2-3).	Colours (ii, 4).	Metals (ii, 12).	Sex (ii, 6).	Elements (ii, 6).	Governing (ii, 1 & 7).	Exaltations (i, 13).	Dejections (i, 13).	Domiciles (i, 14).	Rulers o' the Planets (ii, 5).
SUN . .	Sūrya, Heli* . .	Red . .	Copper . .	Male . .	...	The soul, Kahatriyaa.	Aries . .	Libra . .	10° Leo . .	Agni.
MOON . .	Chandramā, Śīta- raśmi.	White . .	Gems . .	Female . .	...	The mind, Vaisya.	Taurus . .	Scorpio . .	3° Taurus . .	Varuna.
MARS . .	Vakra, Krūrāṇṇik, Āvaneya, Ara* . .	Red . .	Gold . .	Male . .	Fire . .	Vigour, Kaha- triyaa.	Capricorn . .	Cancer . .	28° Aries . .	Kārtikya.
MERCURY . .	Vit, Jīa, Bodhana, Chandraputra, Hemna* . .	Green . .	White metal.	Both . .	Earth . .	Speech, Sūdras.	Virgo . .	Pisces . .	15° Virgo . .	Vishnu.
JUPITER . .	Angirā, Suraguru, Ijya, Vāchaspati, Jiva . .	White . .	Silver . .	Male . .	Sky . .	Knowledge, Brahmans.	Cancer . .	Capricorn . .	5° Sagittarius . .	Indra.
VENUS . .	Sukra, Bhṛigu, Sita Bhṛiguśuta, Aphujit* . .	Blue . .	Pearls . .	Female . .	Water . .	Love, Brah- mans.	Pisces . .	Virgo . .	27° Libra . .	Śachi.
SATURN . .	Manda, Sūryaputra, Asita, Kopa* . .	Black . .	Iron . .	Both . .	Air . .	Sorrow, Lowest castes.	Libra . .	Aries . .	20° Aquarius . .	Prajāpati.

* These are Sanskritised forms of the Greek names of the planets.

4. The rulers of the Signs, &c.

Rulers.	Signs.	Their duodenaries.	Their Novenaries.	Their terms or limits.
Aries . .	MARS	Mars, Venus, etc.	Mars, Venus, etc.	Ma. 5 Sat. 5 Jup. 8 Me. 7 Ve. 5
Taurus. .	VENUS	Venus, Mercury, etc.	Saturn, Saturn, etc.	Ve. 5 Me. 7 Ju. 8 Sa. 5 Ma. 5
Gemini. .	MERCURY	Mercury, Moon, etc.	Venus, Mars, etc.	Ma. 5 Sa. 5 Ju. 8 Me. 7 Ve. 5
Cancer . .	MOON	Moon, Sun, etc.	Moon, Sun, etc.	Ve. 5 Me. 7 Ju. 8 Sa. 5 Ma. 5
Leo . .	SUN	Sun, Mercury, etc.	Mars, Venus, etc.	Ma. 5 Sa. 5 Ju. 8 Me. 7 Ve. 5
Virgo . .	MERCURY	Mercury, Venus, etc.	Saturn, Saturn, etc.	Ve. 5 Me. 7 Ju. 8 Sa. 5 Ma. 5
Libra . .	VENUS	Venus, Mars, etc.	Venus, Mars, etc.	Ma. 5 Sa. 5 Ju. 8 Me. 7 Ve. 5
Scorpio. .	MARS	Mars, Jupiter, etc.	Moon, Sun, etc.	Ve. 5 Me. 7 Ju. 8 Sa. 5 Ma. 5
Sagittarius .	JUPITER	Jupiter, Saturn, etc.	Mars, Venus, etc.	Ma. 5 Sa. 5 Ju. 8 Me. 7 Ve. 5
Capricornus .	SATURN	Saturn, Saturn, etc.	Saturn, Saturn, etc.	Ve. 5 Me. 7 Ju. 8 Sa. 5 Ma. 5
Aquarius . .	SATURN	Saturn, Jupiter, etc.	Venus, Mars, etc.	Ma. 5 Sa. 5 Ju. 8 Me. 7 Ve. 5
Pisces . .	JUPITER	Jupiter, Mars, etc.	Moon, Sun, etc.	Ve. 5 Me. 7 Ju. 8 Sa. 5 Ma. 5

The only other phase of the history of this subject to note now is the interaction between Indian and Muhammadan astrology.

"The Musalman writers mention seven or eight Indian astrologers, whose names, however, it has not as yet been possible to identify with the corresponding Sanskrit. The most important is K-n-k-h or K-t-k-h, who, according to some Arabic writers, appears to have come to Baghdād to the court of the khalif al-Mansur, bringing thither astronomical books of India, and according to others, making known Indian arithmetic. The Arabs attribute to him writings on the *numudar* (that is on the method of ascertaining a factitious ascendant of the nativity), on the nativities, and on the conjunctions of the planets; it is therefore plain that he had also treated of the part of Indian astrology called in Sanskrit *horā* or *jātaka*, which arose through Greek influence."*

On the other hand we note that the common Indian term *Tājaka* applied to works on astrological divination is of Arabic origin, and also that in comparatively modern times the Muhammadan astronomers and astrologers had considerable influence in India.

The chief studies on Indian Astrology are noted below:—

ALBĪRŪNĪ'S India. Edited by E. C. Sachau. Vol. ii, ch. LXXX.

KERN, H. The Brihat Samhitā, or complete system of natural astrology, by Varāhamihira.

Text.—Bib. Indica, 1865.

Translation.—JRAS iv—vi. 1870-1875. Also in his *Versperide Geschriften* Vols. i and ii. See also *Ind. Stud.* x and xiv.

CHATTERJEE, H. P. The Brihajatakam of Varāha Mihira. Allahabad, 1912.

JACOBI, H. Die Astrologiae Indicae 'Horā' appellatae originibus. *Ind. Streife* 1879, 165, 168, &c.

WEBER, A. Zur Geschichte der Indischen Astrologie. *Ind. Stud.* ii (1853) 236-351.

THIBAUT, G. Astronomie, Astrologie und Mathematik (*Grundriss der indo-arischen Philologie*, iii, 9).

APPENDIX II.*

Hindu Astronomical Deities.

VEDIC DEITIES.

In Vedic times there was a group of gods—Sūrya, Savitṛi, Mitra and the other Ādityas—that has, with some propriety, been called a sun-god group. In the Rig Veda, however, the only one of these that is definitely astronomical is Sūrya, who was more closely related with the physical object than the others, occasionally, indeed, being the actual object itself. He was the source of light, the day-measurer, the dispeller of darkness, etc.; Savitṛi, the vivifier, represents a more abstract notion; Mitra was, something like the Mithra of the west, rather vaguely a god of light; while the other Ādityas were still less definitely astronomical.

Although there is nothing in the Rig Veda that marks any one of these gods, except Sūrya, as definitely connected with an astronomical body or phenomenon, yet they are all closely related to Sūrya and even are on some occasions definitely equated with him (and with each other) by name, and also, rather indefinitely, by attributes and functions. The main characteristics of the group may be roughly summarised as follows:—

SURYA. ¹	SAVITṚ. ²	MITRA. ³	ĀDITYAS. ⁴
Son of Aditi ¹ Son of Dyaus ² Produced by various gods ³ Husband of Usha ⁴ = Savitṛi	An Āditya ¹ = Bhaga ² = Mitra ³ = Sūrya	An Āditya ¹ Generally coupled with Varuna. ² = Savitṛi ³	Mitra Aryaman Bhaga Arśa Dakṣa Varuna ¹ Martanda ² Savitṛi ³ Sūrya Indra
Eye of Mitra and Varuna ⁵ A bird ⁶ Chariot with seven horses ⁷	Golden hands, etc. ⁴ Chariot with two horses ⁵		
Measures days ⁶ Dispels darkness ⁷	The vivifier ⁸	Stirs up men and brings them together ⁹	As a group gods of (?) celestial light ⁴
Drives away sickness and evil dreams ¹⁰	Drives away evil dreams, civil spirits and sorcerers ⁷		

2. We have not included in the above group either Pūshan or Viṣṇu. The former is sometimes said to be a sun-god but the connexion is extremely

* Appendix II first appeared in the *Journal of the Asiatic Society of Bengal*, 1920.

¹ (1) RV x, 88¹¹; i, 191⁹; viii, 90¹¹. (2) x, 37¹. (3) ii, 12⁷; ix, 96³; &c. (4) vii, 75². (5) i, 115¹ vi, 51¹; vii, 63¹; x, 37¹; &c. (6) v, 45⁹. (7) i, 50⁸; iv, 13³; v, 45⁹; vii, 60³; but vii, 63³ gives only one steed and in i, 115³, x, 37³, &c., the number is indefinite. (8) i, 50⁷. (9) vii, 63¹; x, 37⁴. (10) x, 37⁴ [AV xiii summarises Sūrya's characteristics].

² (1) viii, 18³. (2) v, 82¹; vii, 38¹; (3) v, 81⁴ (4) i, 35³, ¹⁰; vi, 71³, ⁴; vii, 38³; vii, 45³ (5) i, 35². (6) iii, 62¹⁰ (7) i, 35³; v, 82⁴; vii, 38⁷.

³ (1) ii, 27¹ (2) v, 62; &c.; &c. (3) iii, 59³; v, 81⁴; vii, 36³;

⁴ (1) The first six names are given in ii, 27; see also viii, 18³; &c. (2) x, 72³. (3) vii, 85⁴. (4) A. A. MACDONELL *Vedic Mythol.* 44; but see H. OLDENBERG *Rel. d. Ved.* 185.

loose, although in later times Pūshan is used as a name of the sun.¹ Vishṇu in post-Vedic times became the first of the Ādityas and one of the great gods of the Hindu triad; but in the Rig Veda he holds a subordinate position. He is there characterised chiefly by his 'three steps,' which general opinion, without much warrant, refers to the course of the sun. In one not very clear passage (RV i, 155¹) he appears to be connected with the four quarters of the year, each of which consists of 90 days. In modern times his purely theistic characteristics hide any possible solar relationship.² He has few physical traits left, practically the only one being his anthropomorphic 'three strides.'

3. Other quasi-astronomical deities are the twin Aśvins and Soma. The former have been supposed to be connected with the morning and evening star,³ but their connexion with any astronomical phenomenon is really very vague, although they are often associated with Sūryā, the daughter of the Sūrya.⁴ Their name implies the possession of horses and they have other traits which suggest some parallelism with the Greek Dioskouroi. Aśvinī is the name of the nakshatra usually identified with β and γ Arietis.

Soma is, in the Rig Veda, hardly connected with the moon at all⁵; but perhaps in the later books,⁶ and certainly in the Atharva Veda,⁷ Soma is a name of the moon. In later works the moon as a separate divinity is rarely mentioned and in modern times shares the subordinate position of the planetary gods. Considering the importance of the original Soma and the large part the moon plays in regulating religious practice in India, it is surprising to find that a moon-god proper has no place of importance in the Hindu pantheon.

4. There is some diversity of opinion regarding the relationship of these deities with astronomical bodies. We have, for example, Oldenberg's suggestion connecting the Ādityas with the planets,⁸ and Hillebrandt's theory that the whole Rik is centred round a lunar cult.⁹ But these hypotheses really relate to the remote origins of the Vedic deities and have but little direct bearing on the characteristics of these deities as conceived by the Ṛishis. From our point of view is seen the importance of the fact that in the Rig Veda none of the gods except Sūrya shows hardly any astronomical traits: any astronomical

¹ "The door of the true is covered with a golden disk. Open that, O Pūshan, that we may see the nature of the true. O Pūshan, only seer, Yama Sūryā, son of Prajāpati, spread thy rays and gather them." *Iśa Upan.* 15-16.

² Oldenberg deems that every trace of solar character is lacking in Vishṇu (MACDONELL *Ved. Mythol.* 39); but in the Purāṇas at least, some relationship is indicated, e.g. "The sun, which is the internal unchanging light, is supremely a portion of Vishṇu; and its supreme stimulator is the utterance OM." *Vishṇu Purāṇa* ii, 8.

³ A. A. MACDONELL *Ved. Myth.* 53. Attempts to identify them with the sun and moon have been made.

⁴ Nearly all the references to Sūryā connect her with the Aśvins, as mounting their car, and she appears to be their joint wife. Once she is connected with Pūshan (RV vi, 58⁴), and (I) once with the moon (x, 85).

⁵ See, however, the reference to Hillebrandt's view in the next paragraph.

⁶ e.g. RV x, 85²⁻⁵.

⁷ vii, 81²; xi, 6⁷.

⁸ Oldenberg suggests that Mitra, Varuṇa and the Ādityas are the sun, moon and planets, and that these had been borrowed from the Semites or Sumerians, or had received their astronomical character from them. *Die Religion des Veda*, 185 f. See also O. SCHRÄDER in *ERE* ii, 36.

⁹ *Vedische Mythologie* (Bandl. Soma und verwandte Götter). See also A. A. MACDONELL *Vedic Mythology* p. 113.

connexion there may have been has become obscured. Consequently from the Vedic deities of this type we may not derive the post-Vedic and mediaeval astronomical gods of India.

5. Of Vedic ritual specially applicable to Sūrya there is no information; but, as all the gods were worshipped so, no doubt, was Sūrya, possibly with appropriate ritual. "Adoration to Sūryacelebrate the rite¹ enjoined by him and sing his praise." (RV x, 37¹).

POST-VEDIC.

6. Between the Vedas and any subsequent body of Indian literature there is probably a big time-gap. At any rate the intervening period sufficed to alter considerably the general conception of the celestial deities. In the Atharva Veda there are indications of the coming change. In the Brāhmanas² the Ādityas are twelve and represent the twelve months of the year. Later the whole group became merged into one sun-god, named indiscriminately Sūrya, Sāvitrī, Mitra, Aryman, Pūshan, etc. In the Upanishads the sun is of great importance.³ In the epics a sort of heliolatry is indicated:⁴ the Mahābhārata gives 108 names of the sun:⁵ the Rāmāyana devotes a canto to his praise.⁶ The Jātakas⁷ also refer to the worship of the sun; the Purānas relate solar myths, tell of a race of solar kings⁸ and give in outline the ritual of sun worship that still obtains.⁹

7: Already there are indications of two conceptions of the solar deity that were, possibly, independent of each other or even fundamentally antagonistic—the one being purely Hindu and the other of foreign origin or largely influenced by exotic cults. In Hinduism the sun "is blended so inextricably with the conception of Brahma, beginning with the famous Gāyatrī stanza,¹⁰ as to justify the statement that there is scarcely any theosophic hymn which does not more or less distinctly, primarily or secondarily, have in mind the great heavenly body." On the other hand a solar cult of a less abstract nature, which

¹ The rendering, however, is not certain.

² ŚB vi, 1, 2^a; xi, 6, 3^a.

³ Satyayajna Paulishī meditates on the sun as 'the self' (Ch. U. iii, i¹). "That golden person who is seen, within the sun. . . is the lord of all the worlds" (Ch. U. 1, 6^a—³). Chapter iii of the same Upanishad is a meditation upon the rays of the sun, &c. See also the Kaushitaki Upanishad, ii, 7, etc., etc.

⁴ vii, 82^{1a}.

⁵ iii, 3^a.

⁶ vi, 106. Agastya says—"O mighty Rāma, listen to the old mystery by which thou wilt conquer all the foes in the battle. Having daily repeated the Ādityahṛdaya, the holy prayer which destroys all enemies, gives victory, removes all sins, sorrows and distress, increases life, and which is the blessing of all blessings,—worship the rising sun and the splendid sun, who is respected by both gods and demons, who gives light to all bodies and is the rich lord of all the worlds, etc., etc."

⁷ See nos. 159, 534, etc. Ed. E. B. Cowell.

⁸ Compare the official cult of the *Sol invictus* instituted by Aurelian (A.D. 270-275) and its connexion with the worship of the Emperors. The Chiefs of Udaipur, Jodhpur, Jaipur and Sirmūr claim to be of the 'solar race.'

⁹ VP i, 11, etc.

¹⁰ The Gāyatrī (RV iii, 62^{1a}) is really a Sāvitrī mantra, and it is doubtful whether it originally referred to the sun. It has been rendered thus: May we attain that excellent glory of Sāvitrī the God: So may he stimulate our prayers.

found plenty of justification in the Vedas, but which was probably not altogether indigenous, was in vogue in northern India for a fairly long period.

ASTRONOMICAL MYTHS.

8. Some of the astronomical myths show Vedic origins but most of them belong in spirit to the epic age and some of them show no Vedic relationship at all.¹ The most important of these myths naturally relate to the sun and moon; but, judged by the references in popular literature, by far the best known were those relating to Rohiṇī² and Rāhu.³ In very brief outline the more important myths are as follows:—

The Sun (Sūrya) married Sañjñā, but his light was so overpowering that she gave him Chhāyā (Shadow) as a handmaid. Sañjñā retired into a forest and assumed the form of a mare, but Sūrya, as a horse, discovered her. Among their offspring were the two Aśvins. Sañjñā's father, in order to reduce the Sun's power, placed him on a lathe and cut away an eighth part. From the fragments cut off were produced the discus of Viṣṇu, the trident of Śiva the lance of Kārttikeya, etc. The sun was also a great scholar: he taught the Vedas⁴ to Yājñavalkya,⁵ and to Maya the system of the planets.⁶

The Moon (Chandra), of doubtful parentage, married the 27 daughters of Dakṣha, that is the 27 nakṣatras. Rohiṇī (usually identified with Aldebaran) was the favourite, and the others in their jealousy appealed to Dakṣha, who punished the moon with the disease of consumption, which was afterwards mitigated to the extent of making it periodical only: hence the waning and waxing. A second lunar myth⁷ relates that the Moon carried off Tārā, thereby causing a wide-spread quarrel among the gods. Budha (Mercury) was born to Tārā and the Moon; and from Budha sprang the lunar race.

Mars is said to be the son of Śiva, and is sometimes equated with Kārttikeya, who was also the son of Śiva. Kārttikeya is the god of war and rides a peacock and carries a bow and arrows. He was fostered by the Kṛttikās (? the Pleiades) and hence his name.

Mercury is Budha ('wise') and the son of the Moon and Tārā; Venus (Śukra, 'brilliant') is the son of Bhṛigu; Jupiter is Bṛihaspati or 'Lord of prayer'; Saturn (Sani), the son of the Sun and Chhāyā, always has a malignant influence. Of these four planets no specially significant myths are related.

Rāhu, a semi-reptilian monster, stole and drank some of the *amṛita* of the gods and so became immortal. Viṣṇu thereupon struck off his head, but, as he had secured immortality (for his head at least), Rāhu was placed in the

¹ The only Vedic solar myth relates that Indra stole Sūrya's wheel. RV i, 175⁴; iv, 30⁴.

² e.g. "For blest with Rāma's love is she, As with the Moon's sweet Rohiṇī." Vālmiki's *Rāmāyaṇa* ii, 16.

³ e.g. "Like the fair moon from Rāhu's jaws set free." *Mṛichchhakatikā* iv. See also *Jātakas* nos. 25, 481, 490, 537; *Rāmāyaṇa* ii, 4; 114, iii, 27, 37, 64; iv, 22; vi, 71, etc.

⁴ cf. "Thus the adorable sun, whose self is the Veda, who abides in the Veda and whose self is Vedic knowledge, is called the supreme soul." *Mark. Pur.* cii, 20.

⁵ *Alaṅkāra* India i, 129.

⁶ *Sūrya Siddhānta* i, 1 f.

⁷ VP iv, 6, etc.

heavens. It is said that Rāhu's theft of the *amṛita* was discovered by the Sun and Moon and that in revenge he occasionally swallows them and thus causes eclipses. The myth is, possibly, partly exotic. Astronomically Rāhu became the moon's ascending node, and Ketu, a later introduction, the descending node. There is some confusion in modern texts: Rāhu was called Kabandha, 'headless,' but the introduction of Ketu as *Cauda Draconis* made this nomenclature anomalous.

According to Jacobi, Garuḍa was a sun-god.¹ Vinatā, a daughter of Dakṣha, impatiently opened one of her eggs. It contained a bird (Aruṇa) whose upper half only was developed. Aruṇa became the charioteer of the sun. Vinatā's second egg produced Garuḍa, an enormous bird. He became the servant of the Nāgas, who, however, promised to set him free if he procured for them the *amṛita*. Eventually he vanquished the guardian gods and procured it, in spite of Indra, whose thunderbolt (*vajra*) caused the loss of only one feather. On the ground strewn with *kuśa* grass Garuḍa placed the *amṛita* and invited the snakes to partake of it. While they bathed, Indra, who had become friendly with Garuḍa, carried off the *amṛita*. Garuḍa was rewarded by Viṣṇu who chose him as his *vāhana*, and gave him his standard to rest upon.

There is a quasi-astronomical myth based upon RV i, 71⁵ (and AB iii, 33⁵), which becomes a star picture embracing Sirius, Orion's Belt and Aldebaran. The Taittirīya Brāhmaṇa gives a star picture of Prajāpati, and the Bṛihat Saṁhitā (lviii, 105) gives a *nakṣatra puruṣa*,² which is obviously derived from the *kāla puruṣa* ('time man')—a human figure made up of all the signs of the zodiac—given in the Bṛhajjātaka (i, 4).

MEDIAEVAL SOLAR CULTS.

9. There is abundant evidence, dating from the early years of the Christian era, showing the practice in mediaeval India of a solar cult, and to a more limited extent of a planetary cult also. Philostratus mentions³ a temple of the sun at Taxila; Yājñavalkya and Varāha Mihira give details of ritual;⁴ Yuan Chaung refers⁵ to the sun temple at Multan and to the offering of flowers and perfumes to the image of Sūrya there, and Albīrūnī also mentions⁶ the same temple, of the founding of which there is an account in the Bhaviṣya Purāṇa.⁷ Ānanda Giri, a writer of the ninth century, counted six formal divisions of sun worshippers, of whom some worshipped the rising, some the setting, and some the noon-day sun, others all three as tri-mūrti.⁸ The earliest known Indian inscription referring to this cult is dated A.D. 466, but from that time onward there is plenty of evidence of this type.

¹ ERE ii, 804. It is doubtful, but the myth is given because of its similarity with the Rāhu myth.

² See also the *Matsya Purāṇa*, ch. liv.

³ *Life of Apollonius of Tyana* ii, xxiv.

⁴ See paragraph 13.

⁵ *India*, i, 116.

⁶ BEAL vol. i, 274-275.

⁷ Ch. cxxxix.

⁸ W. HOPKINS *Religions of India*, 447. For a solar tri-mūrti image see H. K. ŚASTRI *South Indian Images of Gods and Goddesses*, fig. 144.

The following are brief quotations from some of the earlier inscriptions: (a) "May that Sun....whom Brāhmanas of enlightened minds, according to due rite.....to be applied to a lamp for the divine Sun."¹ (b) "May that Sun protect you who is worshipped by the host of gods for existence, and by the Siddhas who wish for supernatural powers....who is the cause of the destruction and the commencement of the universe. Reverence to that Sun whom the Brāhmanical sages....failed to comprehend, who nourishes the whole of the three worlds; who, when he is risen, is praised by Gandharvas, gods, Siddhas, Kinnaras and Naras, and who grants desires to those who worship...."² (c) "Let it be known to you that this village is given by me ..to the holy Ādityawith libations of water, to be enjoyed as long as the moon, the sun, and the planets endure....."³

10. Evidence of another type occurs in a work on astronomy. The best known of the mediaeval text-books of this science in India, the *Sūrya Siddhānta* gives the following interesting-account of its own origin:—

"When but little of the Kṛita age was left,⁴ a great Asura named Maya⁵ became desirous of knowing this mysterious, supreme, pure and exalted science—the chief Vedāṅga—in its entirety: the cause namely, of the motion of the heavenly bodies.

"He performed in propitiation of the Sun very severe religious austerities. Gratified by these austerities and rendered propitious, the Sun himself delivered unto that Maya who besought a boon the system of the planets.

"The blessed Sun said: 'Your intent is known to me and I am gratified by your austerities. I will give you the science on which time is founded the grand system of the planets. No one is able to endure my brilliancy For communication I have no leisure.'⁶ This person, who is a part of me, shall relate to you the whole. Go therefore to the city of Romaka where you reside. There, undergoing incarnation as a barbarian, owing to a curse of Brahma, I will impart to you this science.'⁷

GEOGRAPHICAL DISTRIBUTION.

11. The geographical distribution of the temples devoted to the worship of the sun is noteworthy. Most of those of which we now have any record were situated in the north-west of India—from Kāthiāwād to Taxila; but there are remains also in upper Bengal and Orissa. In South India only one, in Tanjore, is known. Images of Sūrya are much more numerous but cover much the same ground. Sculptures of the nine planets are more rare but occur in the same parts of northern India, and at Kolhapur is a so-called Nava-

¹ Indor inscription of Skandagupta, A.D. 465-466. CII iii, 71.

² Mandasor inscription of Kumara Gupta, A.D. 473-474. CII iii, 87.

³ Ragholi plates of Jayavardhana ii (Balaghat) EI ix, 47.

⁴ i.e. some 2,000,000 years B.C.

⁵ Possibly the Avestan Ahura Mazda is meant.

⁶ When Yājñavalkya importuned the Sun to teach him the Vedas, the Sun said: "How is that possible as I must perpetually wander?" *ALSTON India* i, 129.

Whitney thinks the last verse is an interpolation, but it is found in many of the manuscripts.

graha temple. The Śaiva temples of South India are said often to contain images of the planets, but definite records, except for a set at the temple in Tanjore already mentioned, are lacking. Besides these monumental remains there are inscriptions which naturally occur in the same localities, the most interesting being at Gwalior and Bulandshahar. The most notable centres of sun (and planet) worship appear to have been at Mudhera in Gujarāt, Osiā and Sirohī in Rājputāna. Multān in the Punjab and Konārak in Orissa. The (?) solitary South Indian sun temple is at Sūryanārkoṭil in Tanjore.

There is also faint evidence of a separate lunar cult in India. Certain coins of the Kushān rulers of the second century A.D. bear images of a moon-god and there is also the Paurāṇic tradition of a lunar race of kings.¹

MEDIAEVAL RITUAL.

12. The Yājñavalkyasmṛiti, which was possibly composed in the fourth century of the Christian era, contains directions for the worship of the planets:

“Those desirous of prosperity or desirous of peace should worship the planets. For rain, for long life, for nourishment act in the same way. The Sun, Moon, Mars, Mercury, Jupiter, Venus, Saturn, Rāhu and Ketu should be remembered as planets.

“The planets should be offered copper, crystal, red sandal, gold, silver, iron, lead and bronze in order. They should be marked on a board in their own colours in circles by sandal-wood, or their several colours should be indicated by pieces of cloth or flowers. Also perfumes, garlands and incense of *guggulu* should be offered, and oblations should be made with mantras.”

Then are indicated the appropriate mantras, which have a very special interest as obviously they were considered the most suitable of the Vedic texts for the several planets. The connexion, except in the cases of the Sun and Moon, and perhaps, Jupiter, is generally merely a matter of some verbal similarity: for example the Budha (Mercury) mantra begins with *udbudhya*, etc., i.e. “Wake up, etc.” The following translations are taken from Griffith’s edition of the White Yajur Veda.

THE SUN.—“Throughout the dusky firmament advancing, laying to rest the immortal and the mortal, borne in his golden chariot he cometh, Savitṛi, God, beholding living creatures.” (WYV xxxiii, 43; RV i, 35².)

THE MOON.—“Gods quicken me that none may be my rival for domination, mighty lordship, me son of such a man and such a woman, of such a tribe. This is your king, ye tribesmen: Soma is lord and king of us the Brahmans.” (WYV ix, 40.)

MARS.—“Agni is head and height of heaven, the master of the earth is he. He quickeneth the water’s seed.” (WYV iii, 12; RV viii, 44¹⁶.)

¹ The chiefs of Karauli and Jaisalmer claim to be of the ‘lunar race.’

MERCURY.—“Wake up, O Agni, thou, and keep him watchful. Wish and fruition meet and be together. In this and the loftier habitation be seated, All-gods, and the sacrificer.” (WYV xv, 54.)

JUPITER.—“Give us, Brihaspati, that wondrous treasure, that which exceeds the merit of the foeman, which shines among the folk effectual, splendid, that son of law which is might refulgent: taken upon a base art thou. Thee for Brihaspati—This is thy home. Thee for Brihaspati.” (WYV xxvi, 3; from RV ii, 23.¹⁵)

VENUS.—“Prajāpati by Brahma drank the essence from the foaming food, the princely power, the pure bright drinking off of juice. The power of Indra was this sweet immortal milk.” (WYV xix, 75.)

SATURN.—“May the celestial waters, our helpers, be sweet for us to drink, and flow with health and strength for us.” (WYV xxxvi, 12; see also RV x, 9⁴.)

RĀHU.—“What succour will he bring to us, wonderful, ever prospering friend? With what most mighty company?” (WYV xxvii, 39; RV iv, 31¹.)

KETU.—“Thou, making light where no light was, and form, O men, where form was not, wast born together with the dawns.” (WYV xxix, 37; RV i, 6³.)

13. Varāha Mihira (6th cent. A.D.) also gives¹ a faint outline of ritual. His directions are as follows:—

“The Sun and Mars should be worshipped with red flowers, sandal paste, the *vakula* flower, and gifts of copper, gold and oxen to Brahmans. The Moon should be worshipped by the gift of a white cow. Venus should be worshipped with white flowers, and by gifts of silver, and sweet and nutritious things. Saturn should be worshipped by gifts of black substances; Mercury by the gift of gems, silver and with the *tilaka* flower. Jupiter should be worshipped with yellow flowers and by the gift of yellow substances.”

ICONOGRAPHY.

14. Besides the sculptures that have been preserved there is a certain amount of information relating to planetary imagery recorded in the Purāṇas, in the early astrological works, and in the modern *paddhatis* or manuals of ritual, and *pañchāgas* or almanacks.

Separate sun images occur and these are not necessarily connected with the planetary group. These sun images are often very elaborate and exhibit, besides the sun-god himself, a number of attendants.

The whole set of the nine planets, the *navagraha*, is, in early examples, generally shown in relief on a rectangular stone slab, which often formed a temple lintel. Except in the cases of Rāhu and Ketu each planet is shown

¹ *Bṛhat Saṁhitā* civ, 47.

as a human figure—all of them, including the Moon and Venus, being males.¹ To some extent the several deities are differentiated by (a) the symbols or weapons held in the hands, (b) the *vāhanas* or 'vehicles,' (c) colours, (d) materials, (e) special symbols, (f) position, (g) dress, pose, etc.

In the earlier examples the *vāhanas* are seldom, if ever, shown. Possibly the images were sometimes coloured, but evidence is generally lacking.² The special materials were probably only employed in actual worship in connexion with the symbols which represented the planets. The arrangement of the planets in sculpture is generally the week-day order as shown in the tables below, with the sun on the (proper) right³; but in certain ceremonies they (or their symbolic substitutes) are often arranged in some such circular order as is indicated in column F of the table below. The early sculptural representations therefore give us evidence only with reference to the weapons and symbols in the hands, pose, dress and order. Modern representations, pictorial principally but occasionally in brass and stone, show also the different *vāhanas*, etc. The symbolism becomes more complicated with the advance of time, and except in the cases of the Sun, Rāhu and Ketu is now much obscured—the Moon, Mars, Mercury, Jupiter, Venus and Saturn being in many representations almost characterless in their similarity.

In the case of the Sun, besides abundant sculptural evidence, we have Varāha Mihira's explicit directions for its imagery.⁴ "The Sun ought to be made," he says, "with large nose, forehead, legs, thighs, cheeks and breast. In adorning the image the method adopted in the northern countries should be followed. From breast to feet should be covered. He should hold a lotus in each hand, wear a diadem and a necklace; he should be adorned with ear-rings, and a girdle (*avyāṅga*) should be about his waist."

15. Certain details connected with the group of planets are now given in a summary form.

The hands. The symbols, weapons, etc. placed in the hands of the planetary deities vary considerably in modern representations. The practice of giving four arms to each deity is exhibited in none of the early sculptures, but the Matsya Purāna (Ch. XCIV) gives four hands to all except the Sun, Moon and Ketu.

In most cases the Sun carries a lotus in each hand: in northern images the lotus is often full-blossomed, while in the images of Southern India it is said generally to be only half open. Also the northern images sometimes place

¹ But see *Bṛhajjātaka* ii, 6, where the Moon and Venus are, for astrological purposes, considered as female. In India, however, these, as *deities*, are always male; although there are cases on record where Europeans have wrongly described the Hindu Venus as female. Mr. A. Stirling, in 1825 (*Asiatic Researches* xv, 232) described a Konārak sculpture of Venus (figure) as that of 'a youthful female, with a plump, well rounded figure'; and Sir W. W. Hunter (*Orissa* i, 293) repeats this curious error. More recently, in *Bengal Past and Present* (vii, p. 68) is a drawing (not a photograph) of a *navagraha* slab that appears to give Venus a female form.

² The Multan Sun image was, according to Albīrūnī, covered with red leather. (*India* i, 116).

³ In one case at least (Cal. Mus. no. 4182) they are in the inverse of this order.

⁴ *Bṛhat Saṃhitā* lviii, 47.

the hands level with the waist, while in the southern figures they are often raised to the shoulders.¹

There is little consistency in the cases of the other planets, but in several early sculptures Rāhu is shown with huge outspread hands. The pitcher and rosary occur pretty often: the Konārak and Jāgeśvar sculptures give these to each planet except the Sun, Rāhu and Ketu. Mercury in some early cases holds an arrow and has a bow at his side, and Saturn holds a staff or standard. Rāhu appears to hold a vajra in each hand in one case (Konārak) and in another a vajra is placed beneath him. The numerous weapons etc., as given in modern pañchāngas, appear to have little traditional warrant.

MANUAL SYMBOLS.

	SUN	MOON	MARS	MERCURY	JUPITER	VENUS	SATURN	RĀHU	KETU
Agni Purāṇa (ii)	Sword	Rosary, Pitcher	Rosary, Spear	Bow	Rosary, Pitcher	Rosary, Pitcher	Girdle of bells	Half-moon	Sword, Torch
Matsya Purāṇa (xxiv)	Lotus	Club	Lance & Club	Sword, Shield & Club	Staff, Rosary & Pitcher	Staff, Rosary & Pitcher	Lance, Bow & Arrow	Sword, Shield & Spear	Mace
Sculpture Cal. Mus. no. 4168	Lotus	Rosary, Pitcher	Rosary, Spear	Bow, Arrow	Rosary, Pitcher	Rosary, Pitcher	Rosary, Standard		
Konārak	Lotus	Rosary, Pitcher	Rosary, Pitcher	Rosary, Pitcher	Rosary, Pitcher	Rosary, Pitcher	Rosary, Pitcher	Vajra	Rosary, Torch
Modern Paddhatia & Pañchāngas	Lotus, Lotus	Lily	Staff, Pitcher	Trident	Rosary, Pitcher	Rosary, Pitcher	Staff, Pitcher	Half-moon	Rosary, Sword, Shield, Flag

Vāhanas.—Except in the case of the Sun the *vāhana* appears to be a matter of fairly modern fashion. The Sun has a chariot, sometimes with one wheel only,² drawn by seven horses. In one very early case there are, in the Greek fashion, only four horses³; and modern examples often show a single horse with seven heads. According to the Agni Purāṇa (li) the Sun may be represented alone on a horse and there are such examples at Konārak. The Purāṇas generally give a chariot with eight or ten horses to each of the other planets but the modern practice is to give to each a distinct *vāhana*. A Lucknow Museum relief shows beneath the planets in order—a horse, a bird with an animal's head, a peacock, a boar (?), a bird with a horse's head, a frog (?), a horse, a vajra.

¹ T. A. Gopinatha Rao says: "The South Indian figures of Sūrya have, as a rule, their hands lifted as high as the shoulders, and are made to hold lotus flowers which are only half blossomed. . . . The northern images, on the other hand, have generally their hands at the natural level of the hips or the elbows." *Elements of Hindu Iconography*, p. 311.

G. P. xxxix; AP li; Cal. Mus. 5927, etc.

² Arch. Sur. Report, 1908-9, pl. li; R. MITTRA *Buddha Gaya* pl. 1.

Colours.—There is fair unanimity regarding the colours but that of Mercury is somewhat doubtful. In the West also specific colours were allotted to the several planets.

	SUN	MOON	MARS	MERCURY	JUPITER	VENUS	SATURN	RĀHU	KETU
Garuḍa Pu- rāṇa (xxxix)	—	White			Yellow	White	Black		
Mataya Pu- rāṇa (xciv)	Lotus colour	White	White hair	Yellow	Yellow	White	Green	Blue	Smoky
Varāha Mi- hira ¹	Red	White	Very red	Green	Yellow	White or blue	Black		
Paddhatis	Red	White	Red	Yellow	Yellow	White	Black	Black	Smoky
Ptolemy			Red	Variable	White	Yellow	Black		

Materials.—As in the West the materials allotted depend principally on their colours, but the Hindus did not confine the selection to metals altogether.

	SUN	MOON	MARS	MERCURY	JUPITER	VENUS	SATURN	RĀHU	KETU
Varāha Mi- hira ²	Copper	Gems	Gold	Alloy	Silver	Pearls	Iron		
Yāj. Val. Smṛiti	Copper	Crystal	Red san- dal	Gold	Gold	Silver	Iron	Lead	Bronze
Paddhatis	Copper	Crystal	Red san- dal	Gold	Gold	Silver	Iron	Lead	Bronze
Greek	Gold	Silver	Red iron	Tin	Yellow electron	Copper	Lead		

Special Symbols.—The actual images are sometimes replaced by pieces of cloth of the appropriate colour or by pieces of metal of certain shapes or with certain designs engraved upon them. These symbolic designs are of interest as they appear to have some affinity with the western symbols: they are enumerated in the table below.

Dress, etc.—In some early sculptures the Sun and Mercury are distinguished by special head dresses. In one case that of Mercury is particularly noteworthy. In northern images the Sun often wears high boots, a girdle that is supposed to be of Magian origin, and sometimes a sword at his side.

Posture.—In most of the early sculptures the planets are, with the exception of Rāhu and Ketu, standing; and in some of these cases Mercury is particularly differentiated from the others by standing with legs crossed. In several examples Saturn is represented as lame: one of his names is *Paṇḍu* 'the lame,' which is possibly derived from his apparent slow motion. Rāhu and Ketu are sometimes combined in one figure.³

¹ *Bṛihat Saṁhitā* civ. 47; *Bṛihajātaka*, ii, 4-5.

² *Bṛihajātaka*, ii, 12.

³ Lucknow Museum H 100, etc.

The following table roughly summarises the planetary attributes:—

	A The hands.	B Vāhana.	C Colour.	D Material.	E Symbol.	F Position. ¹	G Special features.
SUN . .	Lotus in each hand.	Car with seven horses.	Red .	Copper .	Circle .	Centre .	Magian girdle. ¹ High boots. ² Sword. ³ Coat of mail. ⁷ Attendants. ⁸
MOON . .	Rosary & pitcher.	Car with ten horses (Deer) ² .	White .	Crystal Gems.	Crescent	S.E.	
MARS . .	Rosary & spear	(Ram) ¹ . .	Red .	Red sandal.	Triangle	S.	
MERCURY .	Bow & arrow .	Peacock (Lion ³ with trunk).	Green .	Gold .	Arrow .	N.E.	Stands with legs crossed. ⁹ Special head-dress. ¹⁰
JUPITER .	Rosary & pitcher (Book & sword). ¹	(Elephant or swan). ¹	Yellow .	Gold .	Rectangle Lotus ¹	N.	
VENUS . .	Rosary & Pitcher (Money bag & book). ²	(Horse or frog). ¹	White .	Silver Pearls.	Star Square ¹ .	E.	
SATURN . .	Rosary & Staff	(Vulture or buffalo). ¹	Black .	Iron .	Bow Staff.	W. .	Lame. ¹¹
RAHU . .	Vajra . .	(Lion) ³ . .	Black .	Lead .	—	S.W.	Moon symbol ¹ Bearded. Large canine teeth. Nāga hood. Large hands.
KETU . .	Sword, torch (Flag, shield, spear). ¹	(Vulture) ³ .	Smoky .	Bronze .	Flag ¹ .	N.W. .	Nāga tail.

¹ These are taken from modern paddhatis and panchāṅgas. See also J. BURGESS *Indian Antiquary* xxxiii, 1904, p. 61 ff.

² *Mṛigaṅka* 'marked with a deer' is a name of the moon.

³ Matsya Purāṇa ch. xciv.

⁴ BS civ., 47.

⁵ BS civ, 47 and many sculptures.

⁶ AP li; Cal. Mus. 3928, etc.

⁷ GP xxxix.

⁸ AP li mentions Chhāyā, Kuntī, Piṅgala and 'two damsels with chowries'; GP lxxiii mentions Lāṇḍa and Piṅgala.

⁹ Cal. Mus. 4617, 4618, etc.; Luck. Mus. H 99; etc.

¹⁰ Cal. Mus. 4617, 4618, etc.

¹¹ Luck. Mus. H 99, H 100; Cal. Mus. 4182, 4183.

PRESENT PRACTICE.—*Sun Worship.*

17. The devotions of the pious Hindu are, to a considerable extent, imbued with a sort of astronomical cult, which includes.¹

(a) The recitation, on awakening, of some such mantra as the following:²

“May Brahmā, Viṣṇu, Śiva, the Sun, the Moon, Mars, Mercury, Jupiter, Venus Rāhu and Ketu make the morning auspicious for me.”

(b) The recitation of the Gāyatrī and meditation thereon.

(c) The offering to the Sun of libations of water, accompanied by the recitation of the Gāyatrī and other mantras, *e.g.*

“Salutation to Vivasvat, salutation to the luminous one possessing the energy of Viṣṇu. Salutation to the creator of the world, to Savitrī, the awarder of fruitful deeds.”³

“Come, O Sūrya, of a thousand rays, the storehouse of all the energy of the world. Have mercy on me the sacrificer. Accept this offering, O maker of day.”

(d) Worshipping the Sun and reciting, *e.g.* RV i, 115—

“The Wonderful host of rays has risen, the eye of Mitra, Varuṇa and Agni, Sūrya, the soul of all that moves or is immovable, has filled the heaven, the earth and the air.

“The Sun follows the divine and brilliant Ushas as a man a woman—at which season pious men perform ancient (ceremonies), worshipping the auspicious for the sake of reward.

“The auspicious swift horses of the Sun, well-limbed, road traversing, who deserve to be pleased with praise, revered, by us, have ascended to the summit of the sky, and quickly move round earth and heaven.

“Such is the divinity, such is the majesty of Sūrya, that, when he has set, he has withdrawn what spread over the unfinished work. When he has unyoked his horses from their chariot, then night veils everything in darkness.

“Sūrya in sight of Mitra and Varuṇa displays his form in the middle of the heavens; and his rays extend on one hand his brilliant and infinite power, or, on the other, bring on the blackness of night.

“This day, O gods, while Sūrya is rising, deliver us from grievous sin. May Mitra, Varuṇa, Aditi, Ocean, Earth and Heaven grant this (prayer).”

The following passage from the Viṣṇu Purāṇa (ii, 8) is a naive comment on the practice of sun worship: “The performance of the Samdhyā sacrifice must

¹ The ritual does not appear to be rigidly fixed but some such practice is followed by orthodox Brāhmins. See S. C. VIDYARNAVA *Duty Practice of the Hindus*. See also R. E. ESTROVEN *The Folk-lore of Gujarat* p. 7 ff. Compare the opening verses of Āryabhaṭa's *Gaṇita*, etc.

² Viṣṇu Purāṇa iii, 11. Note also that the Sun is present in the person of a guest.

never, therefore, be delayed; for he who neglects it is guilty of the murder of the Sun. Protected thus by the Brāhmans and the Vāṭakhilyas, the sun goes on his course to give light to the world."

PRESENT PRACTICE—*Planetary Worship.*

17. There is a practice of different type altogether from that just described. The following details pertain particularly to the ceremony connected with the investiture of the sacred thread. On a small vedi about eighteen inches square a lotus with eight open petals is drawn and each of the petals is smeared with the appropriate colour of the planet to which it is assigned. The celebrant places on the lotus figure in the proper order either images of the planets or pieces of metal, etc., stamped with the appropriate symbols, pieces of coloured cloth, and small heaps of rice mixed with curds. But first each piece of metal is washed with the *pañch amṛita* to the accompaniment of appropriate mantras. In setting up the planets the *vyāhṛiti* is recited for each and the attendant deities are addressed and placed on the right and left of each planet. Meditation on the form and symbolism of each planet follows and offerings of special food to each are made.¹ The materials for the sacrifice are then consecrated: special fuel for each planet having been gathered and prepared the *homa* is offered with appropriate mantras. Such is the merest outline² of a very lengthy ritual to which the greater part of a day is devoted. On other occasions (e.g., marriages), a briefer ceremony is practised.³

INFLUENCES.

18. Certain evidence relating to sun and planet worship in India has been given in outline. From Vedic times to the present day some such worship has obtained, but there have been considerable changes. It is obvious that two types of influence have been at work—one pertaining to pure Hinduism, and the other, as pointed out by Sir R. G. Bhandarkar,⁴ of exotic origin. The modern practice of sun worship by the devout Brahman may be traced back to Vedic times, and here the practice is part of the general pantheistic scheme. Planetary worship is probably a foreign importation—possibly of Magian origin, possibly influenced too by the Mithraic teaching that developed to such an extent in the west in the early centuries of the Christian era, and possibly also, to some extent affected by Manichæan practices.

The connexion between Hindu practice and Mithraism is not very marked and probably is evidence only of parallel development, or it may, possibly, indicate some intercommunication. Invoking the sun at dawn, noon and dusk; libations to the planets; the association of particular colours and metals with them, etc., occur in both schemes. Hindu and Mithraic art also have simi-

¹ For details as to the symbols, colours, positions, etc., see the tables in § 16.

² This brief description is based upon a Kumaon Paddhati. See also the *Matsya Purāṇa* Ch. lxxii and lxxiii.

³ For references to sun and planet worship among non-Brahman communities see W. Crooke *The Tribes and Castes of the North-Western Provinces and Oudh* i, 109; ii, 185, 421, 460; iii, 112, 132, 247, 311, 378, 436; iv, 88, etc. T. C. Hodson *The Naga Tribes of Manipur*, 169, 170; *The Meiteis*, p. 103, etc.

⁴ *Foreign elements, etc.* Indian Antiquary XL, 1911, 17 et seq.

larities and might be with some profit compared—for example, certain of the attendants of Sūrya with the Mithraic Dadophori, the Indian Navagraha sculptures on lintels with the Bologna bas-relief, etc.,¹ the Mithraic Kronos with certain figures at Konārak, the Srisailam relief² with certain Mithraic sculptures,³ etc.

For the connexion with Magianism there is more definite information.⁴ According to Varāha Miśra the (Indian) Magas were worshippers of the Sun⁵; the Bhavishya Purāṇa gives their history and refers to a Jaraśasta (Zarathustra) as a son of the Sun, and there is a legend of a son of Kṛishṇa being cured of leprosy by these Magas;⁶ Albīrūnī says:⁷ “There are some Magians up to the present time in India, where they are called Maga”; an inscription of A.D. 1137 mentions them⁸; and there are traces of Maga Brahmans in India to-day. In his *Castes and Sects of Bengal*⁹ Mr. Nagendra Nath Vasu traces the origin of these Magas and gives some account of their position and influence in India. The several legends he relates overlap to some extent but they are very interesting and are here summarised—(a) When Praiyavrata, king of Śākadvīpa, desired to erect a temple and place in it a golden image of the Sun, he brought eight Brahmans, known as Sauryas, from foreign parts. (b) The king, after erecting a temple and placing the image of the Sun in it prayed to the god to provide priests to carry on the worship; and the god created eight Brahmans from the eight parts of his body. (c) The Graha Yāmala relates that the eight Muṇis, Mārkaṇḍa, Māṇḍava, Garga, Parāśara, Bhṛigu, Sanātana, Angirā and Jahnu belonged to Śākadvīpa. Their sons, who were planet worshippers, were by the orders of Śrī Kṛishṇa brought to Sāmbapūr (Multan) by Garuḍa. The descendants of these Śākadvīpī Brahmans and Vaishya women are Gaṇakas. (d) Śaśāṅka, king of Gaur, being ill, sent for certain Maga Brahmans from the banks of the river Sarju (Ghogra). By propitiating the planets these Magas effected a cure and they were persuaded to settle in the country, and the planet worshippers (Graha Vipras) are said to be their descendants.

¹ F. CUMONT *Textes et monuments figurés relatifs aux mystères de Mithra* ii, fig. 99.

² Arch. Report, Southern Circle, 1917-18, pl. xvib.

³ CUMONT, Figs. 121, 150, 151, etc.

⁴ See Sir R. G. BHANDARKAR *Vaishnavism, Saivism & Minor Religious Systems*.

⁵ *Bṛihat Saṃhitā* LX, 19.

⁶ Cf. II Kings, 5.

⁷ *India* I, 21.

⁸ *Epigraphica Indica* ii, 330.

⁹ Vol. ii, part iv. See also the *Archæological Survey of Mayurabhanja*, vol. i p. ii seq.

APPENDIX III.

I. Nakshatras.

Hindu Nakshatras	Usual identifications.	So-called 'Junction Stars.'
1 Kṛittikā . . .	(η Tauri, etc.) . . .	η Tauri.
2 Rohiṇī . . .	(α , θ , γ , δ , ϵ Tauri) . . .	α Tauri
3 Mṛigaśīras . . .	(λ , φ_1 , φ_2 , Orionis) . . .	λ Orionis
4 Ārdrā . . .	(α Orionis) . . .	α Orionis
5 Punarvasu . . .	(β , α Geminorum) . . .	β Geminorum
6 Pushya . . .	(θ , δ , γ Cancri) . . .	δ Cancri
7 Āśleshā . . .	(ϵ , δ , σ , η , ρ Hydræ) . . .	ϵ Hydræ
8 Maghā . . .	(α , η , γ , ζ , μ , ϵ , Leonis) . . .	α Leonis
9 Pūrva-Phalgunī . . .	(δ , θ Leonis) . . .	δ Leonis
10 Uttara-Phalgunī . . .	(β , 93 Leonis) . . .	β Leonis
11 Hasta . . .	(δ , γ , ϵ , α , β Corvi) . . .	δ Corvi
12 Chitrā . . .	(α Virginis) . . .	α Virginis
13 Svātī . . .	(α Bootis) . . .	α Bootis
14 Viśākhā . . .	(ι , γ , β , α Libræ) . . .	ι Libræ
15 Anurādhā . . .	(δ , β , π , Scorpii) . . .	δ Scorpii
16 Jyeshthā . . .	(α , σ , τ , Scorpii) . . .	α Scorpii
17 Mūla . . .	(λ , μ , κ , ι , θ , μ , ξ , μ , ϵ , Scorpii) . . .	λ Scorpii
18 Pūrva-Ashāḍhā . . .	(δ , ϵ Sagittarii) . . .	δ Sagittarii
19 Uttara-Ashāḍhā . . .	(σ , ζ Sagittarii) . . .	σ Sagittarii
20 Abhijit . . .	(α , ϵ , ζ Lyræ) . . .	α Lyræ
21 Śravapā . . .	(α , β , γ Aquilæ) . . .	α Aquilæ
22 Śravishtā . . .	(β , α , γ , δ , Delphini) . . .	β Delphini
23 Śatabhishaj . . .	(λ Aquarii, etc.) . . .	γ Aquarii
24 Pūrva-Bhādrapadā . . .	(α , β Pegasi) . . .	α Pegasi
25 Uttara-Bhādrapadā . . .	(γ Pegasi, α Andromedæ) . . .	α Andromedæ
26 Revatī . . .	(ζ Piscium, etc.) . . .	ζ Piscium
27 Āśvinī . . .	(β , γ Arietis) . . .	β Arietis
28 Bharanī . . .	(35, 39, 41 Arietis) . . .	35 Arietis

2. Precession.

Years.	Degrees.	Degrees.	Years.
1,000 .	13-06	1	71-633
2,000 .	27-02	2	143-265
3,000 .	41-88	3	214-898
4,000 .	55-84	4	286-530
5,000 .	69-80	5	358-163
6,000 .	83-76	6	429-796
7,000 .	97-72	7	501-428
8,000 .	111-68	8	573-061
9,000 .	125-64	9	644-693

3. Longitudes of certain stars (After H. Jacobi,
Ind. Ant. XXIII, 1894, 159).

Name of star.	4,000 B.C.	3,000 B.C.	2,000 B.C.	1,000 B.C.	A. D. 45.	A.D. 560	Asterism in which the star is said to be located.
η Tauri .	341-68°	354-35°	7-08°	19-87°	32-74°	39-97°	Krittikā
α Tauri .	350-46	4-13	16-86	29-65	42-52	49-75	Rohinī
λ Orionis .	5-38	18-05	30-78	43-57	56-44	63-67	Mṛigaśīras
α Orionis .	9-42	22-09	35-88	48-61	61-48	68-71	Ādrā
β Geminorum	34-94	47-61	60-34	73-13	86-00	93-23	Punarvasu
δ Cancri .	50-41	63-08	75-81	88-60	101-47	108-70	Puṣhya
ϵ Hydrae .	54-04	66-71	79-44	92-23	105-10	112-33	Āśleshā
α Leonis .	71-52	84-19	96-92	109-71	122-58	129-81	Maghā
Leonis .	82-96	95-63	108-36	121-15	134-02	141-25	P. Phalguni
β Leonis .	93-32	105-99	118-72	131-51	144-38	151-61	U. Phalguni
δ Corvi .	115-16	127-83	140-56	153-35	166-22	173-45	Hasta
α Virginis .	125-52	137-19	150-92	163-71	176-58	183-81	Chitrā
α Bootis .	125-91	138-35	151-31	164-10	176-97	184-20	Svātī
ϵ Libræ .	152-71	165-38	178-11	190-00	203-77	211-00	Viśākhā
δ Scorpii .	164-28	176-95	189-68	202-47	215-34	222-57	Anurādhā
α Scorpii .	171-44	183-11	196-84	209-63	222-50	229-73	Jyeshthā
λ Scorpii .	186-26	198-93	211-66	224-45	237-32	244-55	Mūla

Names of star.	4,000 B.	3,000 B.C.	,000 B.C.	1,000 B.C.	A. D. 45.	A.D. 560	Asterism in which the star is said to be located.
δ Sagittarii .	196-26	208-93	221-64	234-43	247-30	254-53	P. Ashādhā
σ Sagittarii .	203-06	216-73	229-46	242-25	255-12	262-35	U. Ashādhā
α Lyrae .	206-96	219-63	232-36	245-15	258-02	265-25	Abhijit
α Aquilæ .	223-39	236-06	248-79	261-58	274-45	281-68	Śravaṇa
β Delphini .	238-02	250-69	263-42	276-21	289-08	296-31	Śravishtā
λ Aquarii .	263-26	275-93	288-06	301-45	314-32	321-55	Śatabhishaj
α Pegasi .	275-16	287-83	300-56	313-35	326-22	333-45	P. Bhādrapadā
α Andromedæ .	290-84	303-51	316-24	329-03	341-90	349-13	U. Bhādrapadā
ζ Piscium .	291-54	314-21	326-93	339-73	352-60	359-83	Revati
β Arietis .	315-64	328-31	341-04	353-83	6-70	13-93	Āśvinī
γ Arietis .	327-61	341-28	354-01	6-80	19-67	26-90	Bharanī

4. Cycles, years, months and days.

		Jyotisha Vedāṅga.	Romaka Siddhānta.	Old Sūrya Siddhānta	Āryabhata and Pulisa.	Brahmagupta.	Sūrya Siddhānta.
Years in cycle .	Y	5	2,850	180,000	4,320,000	4,320,000,000	4,320,000
Intercalary months	M_i	2	1,050	66,389	1,593,336	1,593,300,000	1,593,336
Omitted tithis .	D_o	30	16,547	1,045,095	25,082,280	25,082,550,000	25,082,252
Solar months .	M_s	60	34,200	2,160,000	51,840,000	51,840,000,000	51,840,000
Synodic months .	M_i	62	35,250	2,226,389	53,433,336	53,433,300,000	53,433,336
Sidereal months .	M_s	67	38,100	2,406,389	57,753,336	57,753,300,000	57,753,336
Solar days .	D_s	1,800	1,026,000	64,800,000	1,555,200,000	1,555,200,000,000	1,555,200,000
Natural days .	D	1,830	1,040,953	65,746,575	1,577,917,500	1,577,916,450,000	1,577,917,828
Tithis .	D_i	1,860	1,057,500	66,791,670	1,603,000,080	1,602,999,000,000	1,603,000,080
Sidereal days .	D_s	1,835	1,043,843	65,926,575	1,582,237,500	1,582,236,450,000	1,582,237,828

Note. — $M_s = 12 Y$ $D_s = 30 M_i$ $M_i = M_s - M_o$ $M_i = M_s + M_o$ $D_i = 30 M$ $D_o = D_s - D$ $M_s = M_i + Y$ $D = D_i - D_o$ $D_s = D + Y$

5. Sidereal revolutions of planets.

	Āryabhata.	Pulisa.	Brahmagupta.	Sūrya Siddhānta.
SUN .	4,320,000	4,320,000	4,320,000,000	4,320,000
MOON .	57,753,339	57,753,336	57,753,300,000	57,753,336
MARS .	2,296,824	2,296,824	2,296,828,522	2,296,832
MERCURY .	17,937,920	17,937,000	17,936,998,522	17,937,060
JUPITER .	364,224	364,220	364,226,455	364,220
VENUS .	7,022,388	7,022,388	7,022,389,492	7,022,376
SATURN .	146,564	146,564	146,567,298	146,568

6. Revolutions in 4,320,000,000 years of

	APSIDES.		NODES.	
	Brahmagupta.	Sūrya Siddhānta	Brahmagupta	Sūrya Siddhānta
SUN .	480	387	....	....
MOON ¹ .	488,105,858	488,203,000	232,511,168	232,238,000
MARS .	292	204	267	214
MERCURY .	332	368	521	488
JUPITER	855	900	63	174
VENUS .	653	535	893	903
SATURN .	41	39	584	662

Pulisa gives 488,219 and 232,229.

10. Oblique ascensions or periods of risings of signs for certain latitudes.

Signs.		Latitudes.									
		6°	12°	18°	24°	30°	36°	42°	48°	54°	60°
Aries ..	Pisces ..	26° 58'	25° 24'	24° 5'	22° 40'	21° 7'	19° 8'	17° 18'	14° 48'	11° 35'	7° 10'
Taurus ..	Aquarius ..	29° 55'	27° 52'	26° 43'	23° 39'	24° 21'	22° 52'	21° 6'	18° 51'	15° 43'	10° 54'
Gemini ..	Capricornus ..	31° 48'	31° 24'	30° 53'	30° 27'	29° 56'	29° 17'	28° 28'	27° 33'	25° 40'	22° 48'
Cancer ..	Sagittarius ..	32° 33'	33° 2'	33° 30'	33° 59'	34° 30'	35° 9'	35° 18'	37° 1'	38° 34'	41° 38'
Leo ..	Scorpio ..	30° 53'	31° 56'	32° 59'	34° 41'	35° 27'	36° 56'	38° 42'	40° 57'	44° 5'	48° 54'
Virgo ..	Libra ..	29° 3'	30° 22'	31° 41'	33° 6'	34° 39'	36° 26'	38° 28'	40° 58'	44° 11'	48° 36'

11. Tables of Sines.

Arcs. θ.	Ptolemy. Ch'd 2 θ.	Paulisa. Sin θ.	Āryabhata. Sin θ.	Brahmagupta Sin θ.	Arcs. θ.	Ptolemy Ch'd 2 θ.	Paulisa. Sin θ.	Āryabhata. Sin θ.	Brahmagupta Sin θ.
3° 45'	7° 50' 54"	7° 51"	225'	214'	48° 45'	90° 13' 15"	90° 13"	2583'	2459'
7° 30'	15° 39' 47"	15° 40"	449'	427'	52° 30'	95° 12' 9"	95° 13"	2728'	2504'
11° 15'	23° 24' 39"	23° 25"	671'	638'	56° 15'	99° 46' 35"	99° 46"	2859'	2719'
15° 0'	31° 3' 30"	31° 4"	890'	846'	60° 0'	103° 55' 23"	103° 56"	2978'	2832'
18° 45'	38° 34' 22"	38° 34"	1105'	1051'	63° 45'	107° 37' 30"	107° 38"	3084'	2933'
22° 30'	45° 55' 19"	45° 56"	1315'	1251'	67° 30'	110° 51' 52"	110° 52"	3177'	3021'
26° 15'	53° 4' 29"	53° 5"	1520'	1446'	71° 15'	113° 37' 54"	113° 38"	3256'	3096'
30° 0'	60° 0' 0"	60° 0'	1719'	1655'	75° 0'	115° 54' 40"	115° 56"	3321'	3159'
33° 45'	66° 40' 7"	66° 40"	1910'	1817'	78° 45'	117° 41' 40"	117° 43"	3372'	3207'
37° 30'	73° 3' 5"	73° 3"	2093'	1991'	82° 30'	118° 58' 25"	119° 0"	3409'	3242'
41° 15'	79° 7' 18"	79° 7"	2267'	2156'	86° 15'	119° 44' 38"	119° 45"	3431'	3263'
45° 0'	84° 51' 30"	84° 51"	2431'	2312'	90° 0'	120° 0' 0"	120° 1"	3438'	3270'

12. Summary Table (From H. Jacobi, El, i, p. 442).

	Sūrya Siddhānta.	Ārya Siddhānta.	Brahma Siddhānta.
Sun's revolutions in a yuga .	4,320,000	4,320,000	4,320,000
Civil days ..	1,577,917,828	1,577,917,500	1,577,916,450
Lunar tithis ..	1,603,000,080	1,603,000,080	1,602,999,000
Moon's synod. rev. ..	53,433,336	53,433,336	53,433,300
.. sid. ..	57,753,336	57,753,336	57,753,300
.. anom. ..	57,265,133	57,265,117	57,265,194.142
.. nodes ..	—232,238	—232,226	—232,311.168
.. apsides ..	488,203	488,219	488,105.858
Jupiter s ..	364,220	364,224	364,226.455

	Sūrya Siddhānta.	Ārya Siddhānta.	Brahma Siddhānta.
Rev. of sun's apsis in a yuga	387	....	480
Place of sun's apsis at 0 Kali yuga . .	77° 7' 48"	78° 0' 0"	77° 45' 36"
" moon's " " "	90° 0' 0"	90° 0' 0"	125° 29' 46"
" Jupiter's " " "	0° 0' 0"	0° 0' 0"	329° 27' 36"
Circum. of sun's epicycle	14° to 13° 40'	13° 30'	14° to 13° 40'
" moon's " " "	32° to 31° 40'	31° 30'	31° 36' to 30° 44'

13. Modern Values.

	Mean distance.	SIDEREAL PERIOD.		Synodic period in days.*	Sidereal mean daily motion.	Inclination to ecliptic.	Equatorial semi-diameter.*	Mean longitude of the node.	Mean longitude of the perihelion.	Are of retrogression.
		Mean solar days.*	Tropical years.							
Sun ☉	..	..	..	..	..	..	16' 1' 18"	..	..	.. ☉
Moon ☾	..	27.3217	..	29.531	..	5° 8' 43.3"	15' 31.87"	..	..	.. ☾
MARS ♀	1.5237	686.9797	1.8809	779.94	1.88652°	1° 51' 0.9"	4.63"	48° 55' 56.9"	334° 34' 5.4"	.. ♀
MERCURY ☿	0.3871	87.9603	0.2408	115.88	14.73242°	7° 0' 11.6"	3.34"	47° 22' 16"	76° 11' 42.8"	11° ☿
JUPITER ♃	5.2028	4332.588	11.8623	398.88	229.13°	1° 18' 27.7"	1' 37.36"	90° 37' 47.9"	13° 1' 3.6"	9° ♃
VENUS ♀	0.7233	224.701	0.6132	583.92	5.76767°	3° 23' 37.8"	8.40"	75° 57' 2.2"	130° 25' 52.7"	16° ♀
SATURN ♄	9.5388	10759.20	29.4577	378.09	129.45°	2° 29' 29.6"	1' 24.75"	112° 56' 57.3"	91° 27' 30.2"	6° ♄
EARTH ⊕	1.0000	365.2564	1.00004	..	3548.19°	0° 0' 0"	..	..	101° 32' 50.9"	.. ⊕

Solar parallax 8.8"
 General precession 50.2564" + 0.000222 (t — 1000).
 Obliquity of the ecliptic 23° 27' 8.20" — 0.4684" (t — 1000).
 Equatorial horizontal parallax of the moon 57' 2.43".
 Mean distance of earth to moon 384,411 kilometres = 238,862 statute miles or 60.2678 radii.
 Mean distance of earth to sun 149,594,201 kilometres = 92,897,416 miles.
 Length of year:
 Tropical . 365.24219879 — 0.000000014 (t — 1900) days.
 Sidereal . 365.25636942 — 0.000000011 (t — 1900) days.

Length of month:
 Synodical . 29.530588 days = 57d 12h 44m 2.6".
 Sidereal . 27.321561 .. = 57d 7h 43m 11.6".
 Anomalistic . 27.215520 .. = 57d 11h 12m 12.1".
 Length of day:
 Sidereal . 23h 56m 4.091" of mean solar time.
 Mean solar . 24h 2m 56.555" of sidereal time.
 Earth:
 Equatorial radius . 6378.168 kilometres = 3959.26 statute miles.
 Polar radius . 6356.509 kilometres = 3949.89 statute miles.

(All these values except those marked * are taken from the *American Nautical Almanac* for the year 1910).

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ABBREVIATIONS EMPLOYED.

- AB = Aitareya Brāhmaṇa.
AP = Agni Purāṇa.
As. Res. = Asiatic Researches.
AV = Atharva Veda.
BJ = Brihaj-Jātaka.
BS = Brihat Samhitā.
Ch. U = Chhāndogya Upanishad.
CII = Corpus Inscriptionum Indicarum.
EI = Epigraphia Indica.
ERE = Encyclopædia of Religion and Ethics.
GP = Garuda Purāṇa.
Ind. Ant. = Indian Antiquary.
Ind. Stud. = Indische Studien.
JAOS = Journal of the American Oriental Society.
JASB = Journal of the Asiatic Society of Bengal.
JRAS = Journal of the Royal Asiatic Society of Great Britain and Ireland.
JV = Jyotisha Vedāṅga.
MB = Mahābhārata.
MBU = Maitrāyaṇa-brāhmaṇa Upanishad.
PS = Pañchasiddhāntikā.
R = Rāmāyaṇa.
RV = Rig Veda.
ŚB = Śatapatha Brāhmaṇa.
SBE = Sacred Books of the East—Edited by F. Max Muller.
SP = Sūryaprajñapti.
SS = Sūrya Siddhānta.
TB = Taittiriya Brāhmaṇa.
TS = Taittiriya Samhitā.
VP = Viṣṇu Purāṇa.
ZDMG = Zeitschrift der Deutschen Morgenlandischen Gesellschaft.

ADDITIONAL NOTES.

1. The introduction of Greek astronomy.

In the text of this memoir I have not referred to the question, raised by Whitney and others, why certain improvements introduced by Ptolemy into Greek astronomy do not appear in the Indian works of the sixth century onwards. On this basis it has been suggested that the Greek astronomy (and astrology) introduced into India is pre-Ptolemaic. Apparently this means that after about the second century A.D. India accepted no further intellectual material from the west, and in particular it seems to mean that the astronomers of the sixth century onwards knew nothing of Greek astronomical science later than that of the early second century. On the other hand the earliest Hindu-Greek astronomical work known to us is of the early sixth century A.D.¹

Whitney definitely suggests that Greek astronomy came to India by the sea route, and not overland, before the time of Ptolemy. His arbitrary closure of the land route is unacceptable; and, of course, in the first and second century A.D. a good deal of western astrological and astronomical lore was current in, say Ujjain and Taxila. No one would deny that; but it is difficult, if not impossible, to accept the suggestion that no further western knowledge found its way into western India after the publication of Ptolemy's great work. Either that is meant or, possibly, it is meant that the Hindu astronomers rejected part of Ptolemy's teaching, and stuck to a Greek tradition that had been handed down to them from pre-Ptolemaic times.

As a matter of fact the conditions that hold are normal enough. The Hindu astronomers of the period took just what they wanted from the western works that reached them. They were not overwhelmed with the renown of Ptolemy and it is quite possible that many Alexandrian text-books of the fifth century neither mentioned him nor his improvements (which indeed in Whitney's time were rather exaggerated). Undoubtedly Varāha Mihira had Greek text-books at hand and his exposition of his subject seems to indicate that he was introducing new ideas, or, at least, ideas and terms that were not common; and certainly some of these notions are post-Ptolemaic. The surprise is, not that there are points of difference, but that there is such close correspondence.

The persistence of old ideas and the neglect of new ones are among the commonest phenomena pertaining to the history of intellectual development. Indeed these phenomena have prevailed (and still prevail) with 'the school-men' of almost every country. In India, during the period under consideration, a phase of intellectual assimilation obtained and the preserved records exemplify this fashion in no particularly abnormal way.

¹ The work of Yavaneśvara or Āsphujidrāja discovered by MM Hari Prasad Shastri in Nepal (JASB, 1897, 311) possibly belongs to the third century A.D. but is valueless. See also Dr. V V. Ramana-Sastriy in *The Classical Review* 1922, p. 20.

2. Buddhist astronomy.

According to Vinaya ii, 217,¹ a monk who lives in the forest is to learn the positions of the nakshatras, either the whole or one section, and is to know the cardinal points.' At the end of the ordination service the process of 'measuring the shadow' is performed in order to determine the seniority of the monk, and he is instructed in the length of the seasons and division of the day. * * * The earth, a flat disc, is 1,203,450 yojanas in diameter and 3,610,350 in circumference. In the centre is Mt. Meru, rising 84,000 yojanas above the surface of the earth, and round it circle the sun, moon and stars, shining in turn on the four continents round Mt. Meru. The diameter of the moon is 49 yojanas and the circumference 147; of the sun 50 and 150 respectively. The sun is one yojana higher in position than the moon.²

¹ *SBE*, xx 294.

² E. J. Thomas, *ERE*, xii, 71.

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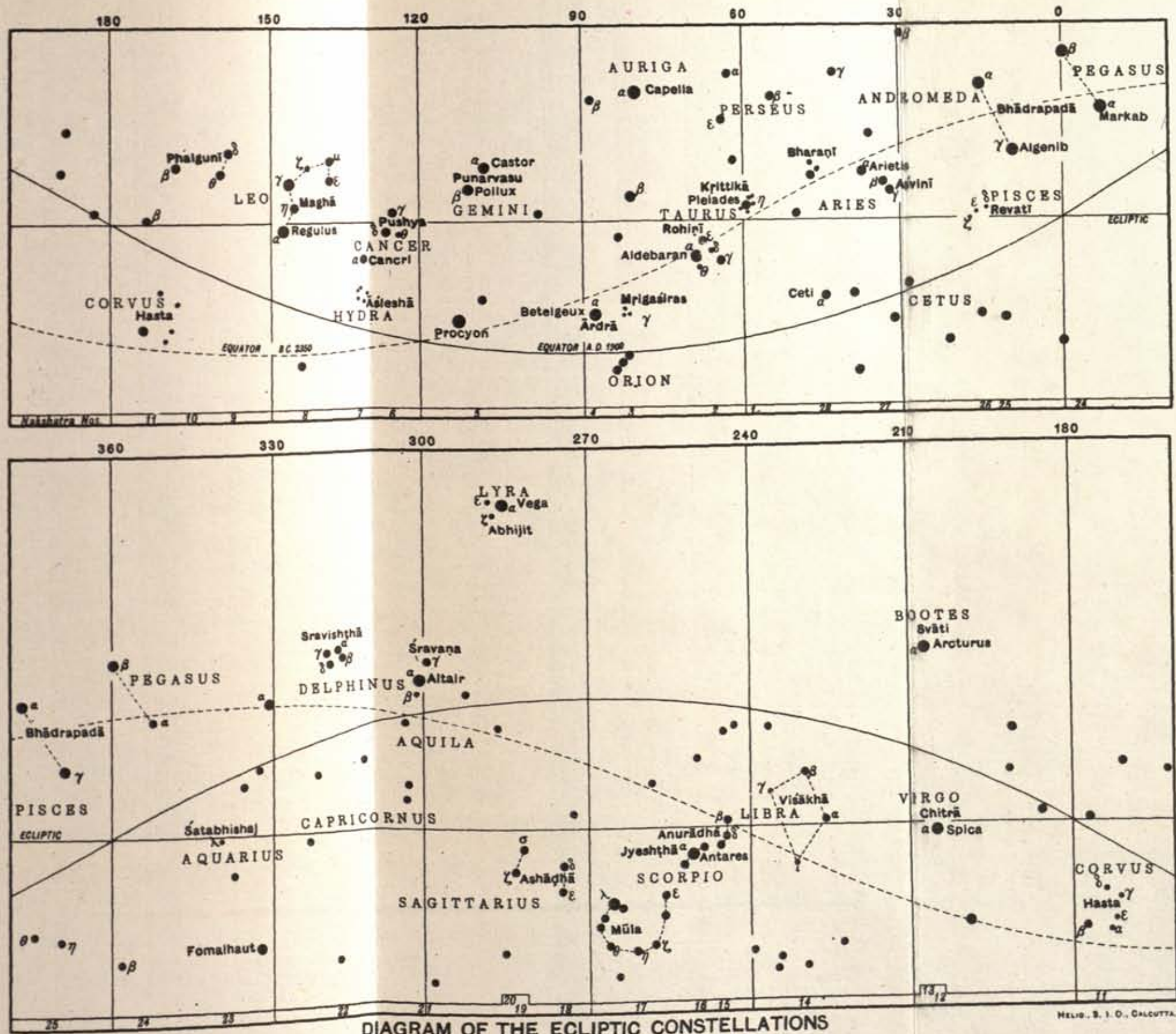


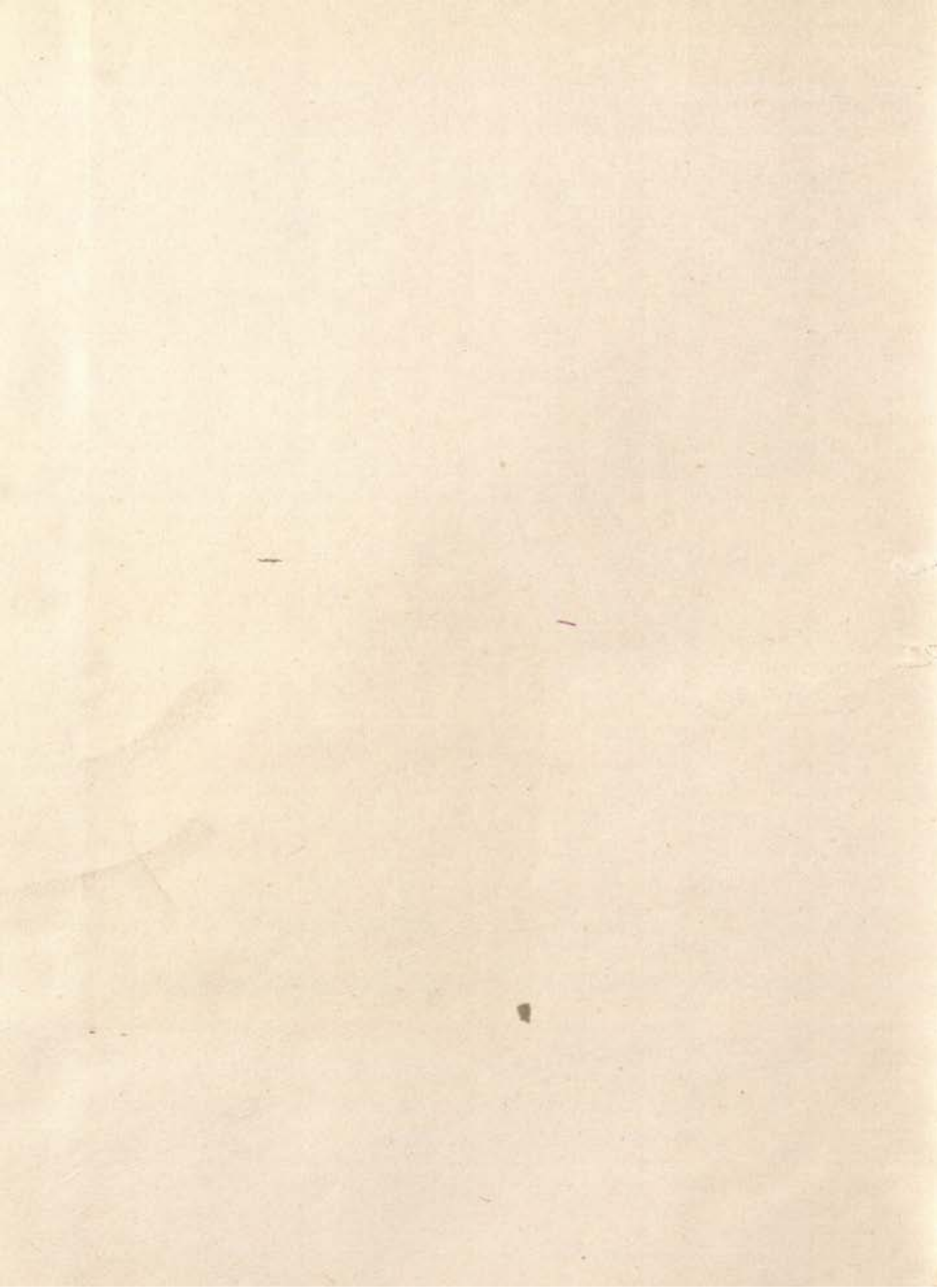
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